National Roadmap for Adaptation 2100

Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

REPORT

WP3 – EMISSIONS SCENARIOS, NARRATIVES, AND SOCIOECONOMIC TRAJECTORIES

Final Version

National Roadmap for Adaptation 2100

Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

---

Title: RNA2100 - Emissions Scenarios, Narratives, and Socioeconomic Trajectories
Authors:Pedro Matos Soares (coord.), Luís Filipe Dias, Jiesper Pedersen, Susana Marreiros, Filipe Duarte Santos, Rita Cardoso, Pedro Matos Soares, Rob Swart, James Edmonds, Detlef van Vuuren & Katherine Calvin.

February 2024

This report is a product of the National Roadmap for Adaptation 2100 project.
Through the Agreement on the European Economic Area (EEA), Iceland, Liechtenstein and Norway are partners in the internal market with the Member States of the European Union.
In order to promote a continuous and balanced strengthening of economic and trade relations, the parties to the EEA Agreement have established a and trade relations, the parties to the EEA Agreement established a multi-annual Financial Mechanism, known as the EEA. known as EEA Grants.
The EEA Grants aim to reduce social and economic disparities in Europe and to strengthen bilateral relations between these three countries and the beneficiary countries.
For the 2014-2021 period, a total contribution of 2.8 billion euros has been agreed for 15 beneficiary countries. for 15 beneficiary countries. Portugal will receive 102.7 million euros.

Funded by:

Promoter:

Partners:

Table of Contents

Proposed Tasks

Tasks	Status
Identification (data nature, format, and resolution) and provision of contextual information useful as inputs to sectoral impacts modelling (WP4), identification of adaptation needs (WP5), and macroeconomic model (WP6).	Done
Consideration of one specific socioeconomic scenario for each of the GHG concentration scenarios (RCP2.6, RCP4.5 and RCP8.5).	Done
Consideration of the Shared Socioeconomic Pathways (SSPs) with further adjustments to improve the coherence to the national context.	Done
Adjustment to Portuguese circumstances with the socioeconomic scenarios under the national Carbon Neutrality Roadmap 2050.	Done
Regionalize, as possible, the socioeconomic scenarios, particularly for sectors with high territorial expressions (e.g., *montado*).	Done
Contribution of the socioeconomic scenarios to define the sectoral narratives as well as national GDP and population projections, for the two distinct periods 2041-2070 and 2071-2100.	Done

Deliverables

WP3A	Project report chapter “Emissions scenarios, narratives, and socioeconomic trajectories”
WP3B	Scenarios tables with the indicator figures

1. Introduction

Anthropogenic climate change and its challenges extend far into the distant future (IPCC, 2021; le Quéré, 2004; NRC, 2010). Scientific knowledge has played a key role in understanding and acting on climate change as a political issue on global and national levels (Lahn, 2018; Pedersen et al., 2022a). This report explores approaches for developing and analyzing socio-economic scenarios (narratives and trajectories) for Portugal. The approaches are based on information developed in multiple areas and scenario series at global to national and regional scales. The information sources comprise i) information from the socio-economic scenarios developed for the United Nations Intergovernmental Panel on Climate Change (IPCC) between the fifth and sixth assessment report on climate change (2013-2022), ii) other international scenario sources, and iii) information from national scenario sources, namely the National Statistics Institute (INE) and the Portuguese Roadmap for Carbon Neutrality 2050 (RNC2050). In this context, we compiled or developed projections of different socio-economic and land use variables for Portugal, seeking to justify the choice of a specific scenario that will be applied throughout the RNA2100 project (link). Thus, the report serves to provide a critical analysis to build plausible narratives for a future Portugal.

Furthermore, the report builds on top of a scientific paper produced within the RNA2100 project, which provided the first comprehensive review of the evolution of the emission scenarios informing the IPCC, since 1990. The paper provides an overview and analyzes of emission scenario critiques (e.g., evaluations and assessments), serving to prepare future scenario updates (Pedersen et al., 2022a) and a basis for evaluating the most recent scenario generation in this report. Socioeconomic emission scenarios comprise one crucial tool cutting across the three IPCC Working Groups (WGs). The four generations of emission scenario series/generations within the IPCC context (Gidden et al., 2019a; Richard H. Moss et al., 2010) are grounded in the work of WG3 (climate change mitigation) and used by scientists in research informing WG1 (climate science) and WG2 (climate impacts and adaptation) communities as essential bases for analyzing future climatic changes. The four generations of emission scenarios informing the Intergovernmental Panel on Climate Change's (IPCC) assessments (IPCC, 1990a; Richard H. Moss et al., 2010) include the "1990 IPCC First Scientific Assessment" (SA90) (IPCC, 1990a), the "1992 IPCC Scenarios" (IS92 series) (Leggett et al., 1992a), and the 2000 "Special Report on Emissions Scenarios" (SRES) (Nakicenovic and Swart, 2000a). They also include more recent scenarios developed outside the IPCC (Richard H. Moss et al., 2010), i.e., the "Representative Concentration Pathways" (RCPs) (van Vuuren et al., 2011a) and the "Shared Socioeconomic Pathways" (SSPs) (O'Neill et al., 2014; Riahi et al., 2017a).

1.1 Historical and projected climate change

Climate change is an increasing global concern. Changes in land use and greenhouse gas (GHG) emissions, primarily due to human action, produce profound changes in the climate system and modify climate patterns (IPCC, 2007a). The most recent IPCC report on impacts, adaptation, and vulnerability describes the global scientific consensus that climate change will cause many parts of the planet to become unlivable in the next few decades (IPCC, 2022a). These assessments are made via input from emission scenarios (SSP-RCPs), describing plausible socioeconomic futures (Gidden et al., 2019b; IPCC, 2022a).

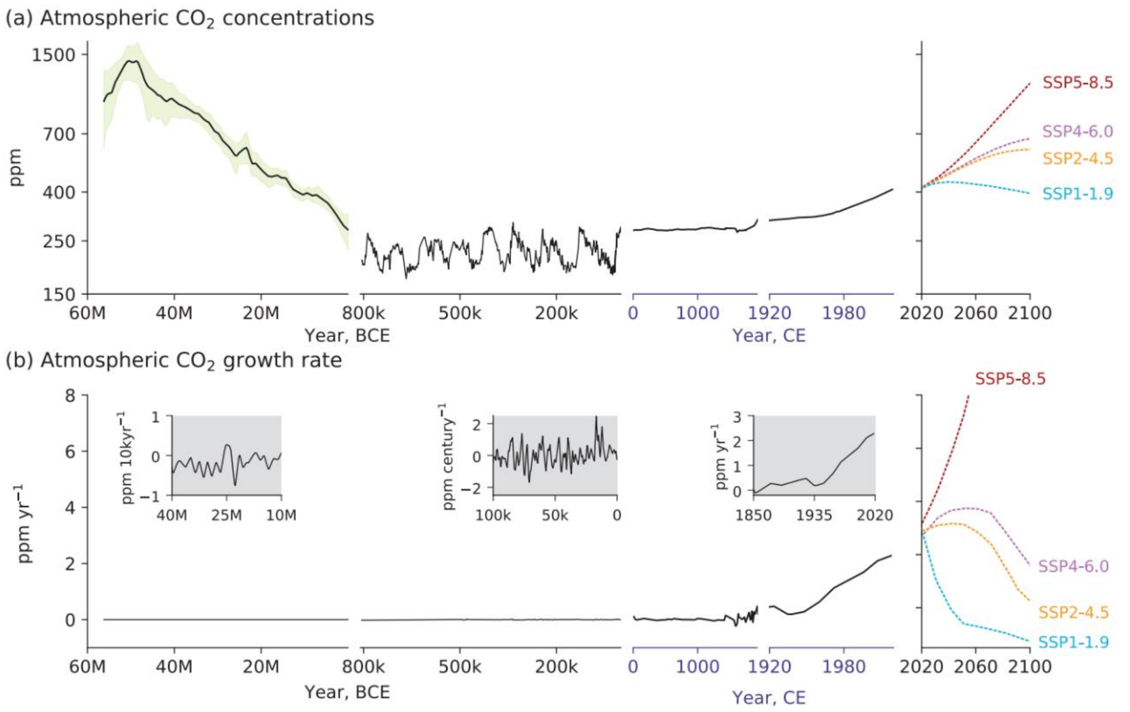


Figure 1. Atmospheric CO_2 concentrations and growth rates for the past 60 million years (Myr) and projections to 2100. Source: IPCC (2021)

Anthropogenic carbon dioxide (CO_2) is the GHG, besides water vapor, that causes the most significant radiative forcing1 in the atmosphere. Its emission originates mainly from burning fossil fuels (oil, coal, and natural gas) and deforestation. Methane (CH_4) and nitrous oxide (N_2O) are also essential gases concerning anthropogenic climate change (after this, referred to simply as climate change) (Cloy and Smith, 2018). Recent data indicate that the concentration of GHGs in the atmosphere is currently the highest in the last 800 thousand years. The average concentration of CO_2 reached 400 parts per million (ppm) in 2016, which is 40% higher than in the pre-industrial era (EEA, 2017).

[1] Radiative forcing quantifies changes in energy flows caused by changes in natural and anthropogenic substances and processes that alter the Earth's energy balance IPCC (2013).

The increase in the global average temperature is the primary manifestation of climate change. During 2001–2020 and 2011–2020 global surface temperature was about 0.99°C (0.84-1.11 °C) and 1.59°C (1.34-1.83 °C) higher, respectively, compared to the preindustrial period (1850–1900). Over land, the increases were almost double as high (1.59 °C [1.34 - 1.83°C]) than over the ocean (0.88 °C [0.68 to 1.01°C]), when compared 2011–2020 to preindustrial levels (APA, 2019; IPCC, 2021). In Europe, land temperatures increased faster than the mean value over land for the world, being 1.94 to 2.01°C warmer when compared the 2012-2021 decade with the pre-industrial period (EEA, 2022; IPCC, 2021).

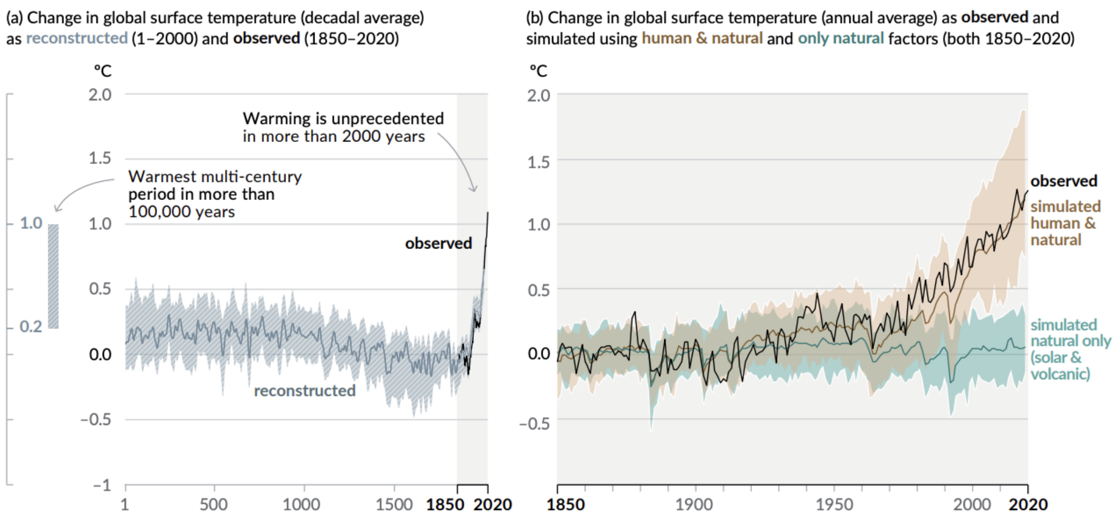


Figure 2. Changes in global surface temperature relative to 1850–1900. Source: IPCC (2021)

Impacts of climate change are caused by slow onset and extreme events (IPCC, 2022b). In summary, the Mediterranean region has experienced increasing temperatures and agricultural droughts (low soil moisture) due to climate change (IPCC, 2021). If politicians do not manage to implement efficient mitigation policies, the impact from floods (sea level rise) and droughts (e.g., forest fires) is projected to increase remarkably. In case of continuation of historical (mitigation) trends, global temperatures could reach about 2.6-3.2 °C by 2100 (SSP2-4.5, SSP4-6.0). Fulfilling the Paris Agreement and staying below 1.5 °C by 2100, will still cause increasing climate impacts, however less frequent and severe than a continuation of the current societal dynamics (IPCC, 2022c, 2022b). Historically, the US (25%) and EU (17%) are responsible for the largest number of historical global cumulative fossil fuel and industry CO_2 emissions (Ritchie and Roser, 2018).

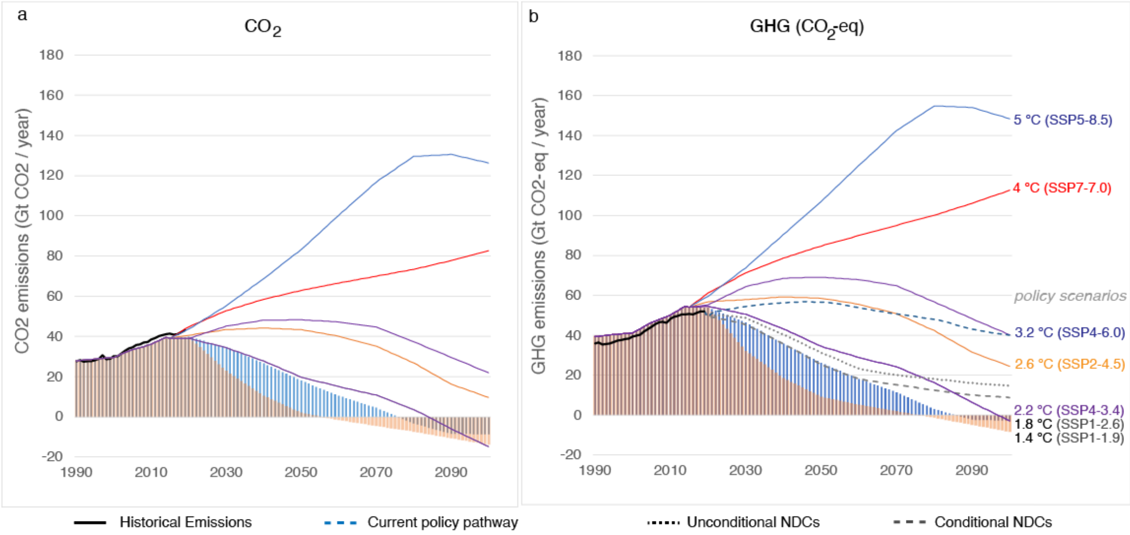


Figure 3. Total CO_2 (a) and Kyoto GHG emissions (b) over the past three decades compared with the SSP-RCP emissions scenarios and the Climate Action Tracker (CAT) short-term policy scenarios assessing the effect of national mitigation policies and the Paris Agreement Nationally Determined Contributions (NDCs). Inconsistency between historical and projected emissions in GHG (b) may be caused by differences in dataset used by the SSP and CAT. Data sources: SSP database (Riahi et al., 2017), Historical CO_2 from the Global Carbon Project (GCP, 2020), Historical GHG, and policy projections from Climate Action Tracker (2021a).

Increasing global mean temperature is projected to cause impacts. They will appear as slow onset and extreme events. Slow onset events are "increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea level rise and salinization" (IPCC, 2022b). It is virtually certain that the frequency of extremes of heat will increase in most continental areas, in contrast to extremes of cold that will be less and less frequent, both in daily and seasonal terms (IPCC, 2014b). An example of extreme events is heat waves, for which an increase in frequency, intensity, and duration is expected. These changes will have consequences for different vulnerabilities, such as **forest fires** and **droughts**, globally (IPCC, 2022b) and particularly in (Southern) Europe (Costa et al., 2020). Figure 4 shows the historical impacts on ecosystems. The green boxes highlight the Mediterranean region and Africa, where Portugal has several historical related commitments to support adaptation and mitigation, e.g., financing energy transition and research on how to ensure future food security in Angola and Mozambique, which face severe impacts.

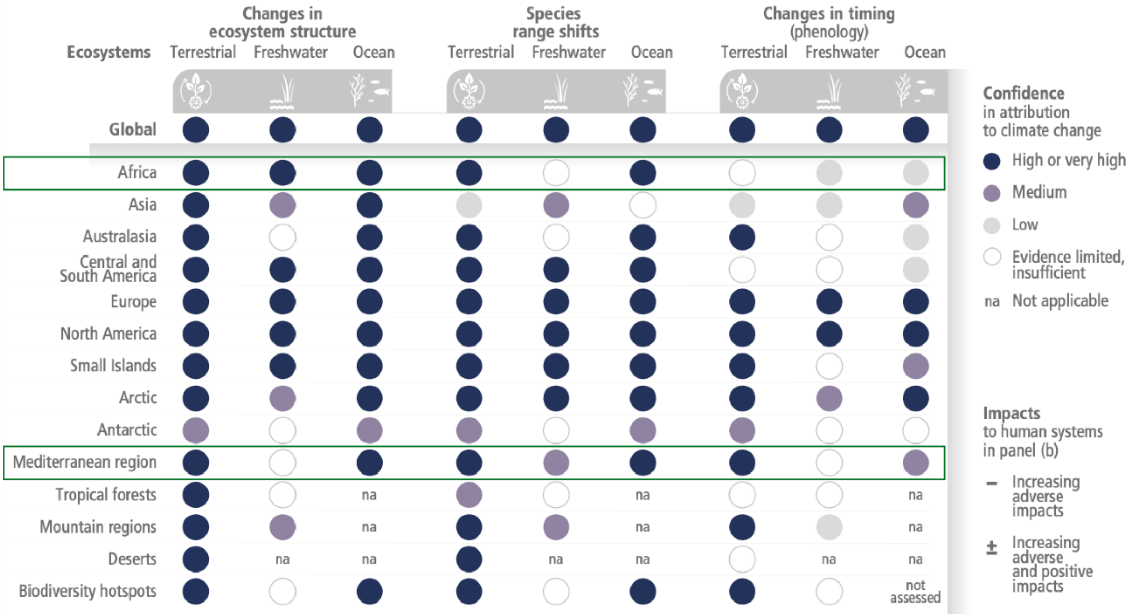


Figure 4. Observed global and regional impacts of climate change on ecosystems. Source: IPCC (2022b).

Increasing global temperatures causes **rise in mean sea level**. This results from the expansion of ocean surface waters, the melting of mountain glaciers, and the melting of glaciers and ice fields situated above sea level and land in the polar regions. Between 1901 and 2018 global mean sea level increased by 0.20 meters. The increase happened at a faster rate between 2006 and 2018 (3.7 mm yr^{-1}), than between 1971 and 2006 (1.9 mm yr^{-1}), and 1901 and 1971 (1.3 mm yr^{-1}) (IPCC, 2021). According to the IPCC (2021) throughout the 21st century, the ocean will continue to warm, and the mean sea level to rise. Furthermore, sea-level rise will not be uniform in all regions (IPCC, 2021, 2014b). During this century, sea level change along most European coastlines is projected to be reasonably like global changes (IPCC, 2022a). Global mean sea level levels are projected to increase in the range of 0.28-0.55 m for the lowest emission scenario (SSP1-1.9 equivalent to the 1.5 °C Paris target). For the middle-of-the-road scenario with moderate political mitigation efforts (SSP2-4.5) and the high emission scenario (SSP5-8.5) projections show 0.44-0.76 m and 0.63-1.02 m, respectively (IPCC, 2021). Depending on the methods of comparison the World has historically the past three decades been on an emissions trajectory that could fit a SSP2 and SSP5 scenario (Pedersen et al., 2021, 2020).

In case that global mean sea level rises by 0.15 m relative to 2020, the population potentially exposed to an extreme coastal flood event is projected to increase by about 20%. The exposed population doubles at a 0.75 m rise in mean sea level and triples at 1.4 m. This, without considering population change and additional adaptation (IPCC, 2022a).

Concerning **precipitation**, the global variation projected for the future climate is not uniform. Increasing intensity and frequency of extreme precipitation is experienced since the 1950s forced by human-induced climate change and causing more agricultural and ecological droughts, i.e., periods of abnormal soil moisture shortage. On the other hand, the number of daily extreme rain events are projected to increase by 7% for each 1°C increase in global mean temperature (IPCC, 2021).

1.2 Mitigation and adaptation

One of the most highlighted aspects in the previous IPCC assessment (AR5) is that, even if anthropogenic GHG emissions ceased immediately or climate forcings were fixed at current values, the climate system would continue to change until it reached a balance with these forcings. This is due to a slow response of some climate system components, such as the atmosphere (the long lifetime of some GHGs) and the oceans (thanks to their high inertia in the absorption of heat), preventing conditions from reaching equilibrium for centuries (IPCC, 2014b).

In this sense, limiting global warming to 1.5°C compared to the pre-industrial period is imperative, requiring rapid and profound transitions in the management of land use, energy, industry, buildings, transport, and cities. Global warming of up to 1.5°C will have less impact on terrestrial ecosystems, wetlands, and the preservation of ecosystem services than higher warming, where the effects will be irreversible for some species and ecosystems, on their ecological functions and services provided by these to humanity (IPCC, 2018).

The risks to natural and human systems are also lower for global warming at 1.5°C compared to 2°C. However, this depends on the geographic location, the levels of development, the vulnerability, and the adaptation choices adopted (i.e., dealing with the impacts of unavoidable extreme events and their environmental, economic, and social costs).

Global net CO_2 emissions need to decline by around 45% from 2010 levels by 2030 and reach carbon neutrality[2] by 2050 to achieve the 1.5°C goal (IPCC, 2018).

Implementing policies to limit warming to 1.5°C successfully and adapt to this warming implies international cooperation and strengthening the institutional capacity of national and regional authorities, civil society, the private sector, cities, and local communities.

In the current context of uncertainty in world climate policy, it is essential to adapt to the negative impacts of climate change, bearing in mind that the adaptation process may not be sufficient to avoid all these impacts.

Paradoxically, a national, regional, or local policy exclusively based on mitigation may have a residual contribution to the reduction of concentrations of greenhouse gases in the atmosphere,

[2] Balance between the amount of carbon emitted and the amount of carbon sequestered.

not reducing the impacts of climate change, if at a global level there is no concerted effort of mitigation (Klein et al., 2005).

As climate change is a very complex process with high risks for humans, ecosystems, and material goods, it is vital to promote adaptation in a structured way by implementing effective measures that reduce vulnerability and increase the resilience of systems (EEA, 2017; IPCC, 2022b).

1.3 The socio-economic scenarios developed for the IPCC

The Intergovernmental Panel on Climate Change reports have been accompanied by a constant evolution of climate projections, greenhouse gas emission scenarios, and the socio-economic scenarios that support these projections.

The first generation of these scenarios was called SA90. It was used in the first IPCC report, comprising four scenarios, two without climate policies and two containing these policies (see Annex II).

The second generation was designated IS92, comprising six scenarios and a higher emissions range, including two high-emission scenarios higher than the SA90 BaU and the most pessimistic scenario (IPCC, 1990). The IS92 emissions range was higher than the SA90. In addition, the mitigation policy assumptions and the BAU label were excluded because of intergovernmental arguments. Thus, this new IPCC mandate (IPCC, 1991) compromised the scientific credibility of the scenarios. However, it was important for political reasons (Pedersen et al., 2022). The SA90 update - the IS92s - was used in the second IPCC assessment report (see more Annex II).

The third generation was designated SRES (Special Report on Emissions Scenarios), the first to integrate future development narratives in its formulation, seeking to cover two axes: economy versus environment and another related to globalization versus regionalization. Four narrative families were created (scenario families A1, B1, A2, B2) and two illustrative scenarios from the A1 family (A1F and A1T). These informed (rather than being used for direct assessment in) the IPCC's third and fourth assessment reports, marking a difference compared to the 1st and 2nd IPCC reports.

The current generation of scenarios (4th generation) has a different formulation from the previous ones. Initially, two sets of pathways were developed in a parallel process - climate/radiative forcing trajectories (Representative concentration Pathways - RCP) and socio-economic scenarios (Shared Socioeconomic Pathways - SSP). Only the RCPs (climate trajectory scenarios) informed the 5th IPCC report (AR5). Subsequently, both scenarios were made compatible through assumptions that illustrate the key characteristics of the climate change adaptation and mitigation policy (Shared climate policy Assumptions - SPA), and the sixth IPCC report was developed based on this set of scenarios and assumptions.

1.3.1 The RCP Climate Scenarios (Representative Concentration Pathways)

Climate scenarios result from projections of the response of the Earth's climate system to scenarios of greenhouse gas emissions or concentrations. Projections in climate change scenarios currently available by the IPCC are called RCP (Representative concentration Pathways). The RCPs comprise four trajectories of greenhouse gas concentrations in their original form, developed to explore a wide range of possible climate futures (van Vuuren et al., 2011). They are increasingly organized in terms of the concentration of these gases in the atmosphere by 2100: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (IPCC, 2013; van Vuuren et al., 2011a).

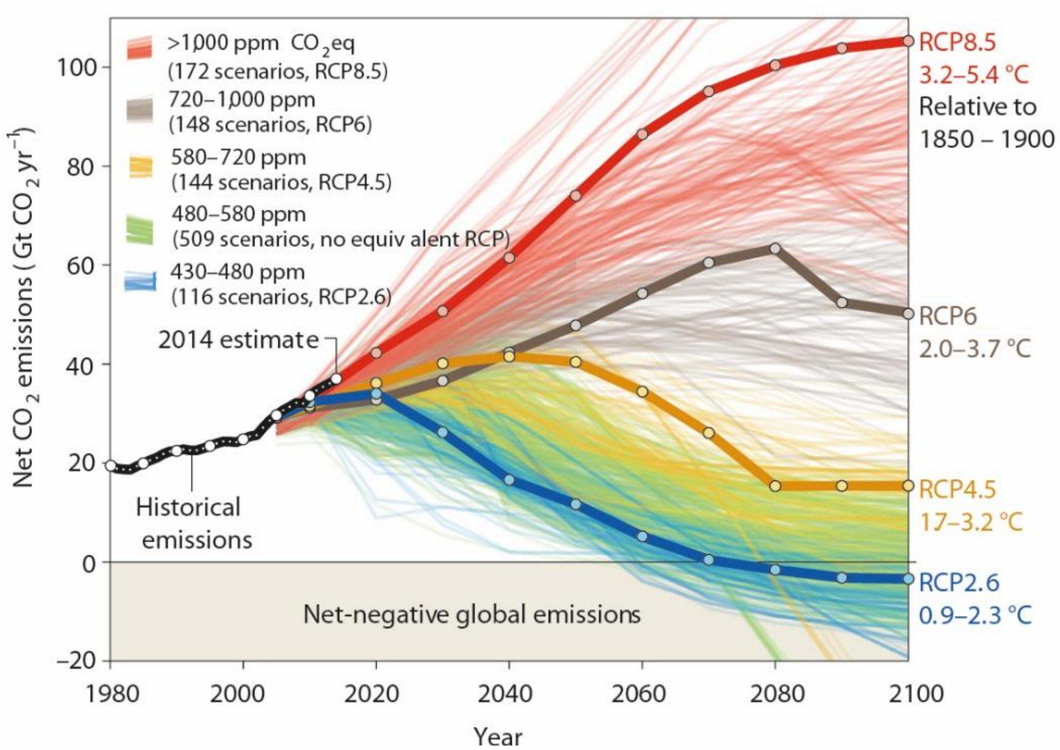


Figure 5. Carbon dioxide emissions up to 2100 and emissions history (in black). Source: adapted from Fuss et al. (2014)

The RCP4.5, RCP6.0, and RCP8.5 can represent baselines (i.e., no mitigation or no intervention scenarios) projecting medium-low, medium, and high levels of future emissions, respectively. However, the RCP4.5 and RCP6.0 can additionally express moderate mitigation (Pedersen et al., 2020), while the RCP2.6 scenario is a climate change mitigation scenario, implying considerable climate policies (van Vuuren et al., 2011a). The RCPs cover the spectrum of scenario literature on future emission levels. These scenarios represent different radiative forcings in 2100, and their emission trajectories are partially inspired by the Special Report on Emissions scenarios (Nakicenovic and Swart, 2000a), published by the IPCC in 2000 (IPCC, 2013).

Three of the four RCPs will be applied within the scope of the National Adaptation Roadmap (RNA2100), excluding RCP6.0.

RCP2.6 assumes an increase in radioactive forcing at the tropopause of 2.6 W/m^2 by 2100 relative to the pre-industrial era (1850-1900). It is equivalent to a projected increase in the global average temperature between 0.9°C and 2.3°C (IPCC, 2013). In this scenario, it is unlikely[3] that the global average temperature will exceed an increase of 2°C, so it is the scenario that best characterizes the objectives of the Paris agreement.

RCP4.5 (4.5 W/m^2 by 2100) projects a global mean temperature increases between 1.7°C and 3.2°C (IPCC, 2013). It is more likely than unlikely[3] that it does not exceed 2°C in this scenario (IPCC, 2013).

The **RCP8.5** scenario is sometimes assessed to a trajectory which track closely to observed greenhouse gas concentrations in recent years (Fuss et al., 2014; Pedersen et al., 2020; Schwalm et al., 2020) (Figure 5). This trajectory assumes an increase in radiative forcing of 8.5 W/m^2 towards the end of the century, and it is equivalent to global average temperatures between 3.2°C and 5.4°C (IPCC, 2013).

The RCP8.5 concentration pathways has been called into question since AR5, as has the emissions pathway feasibility of the low scenarios (IPCC, 2022). However, these views are contested, being important to realize that emissions scenarios and concentration pathways are not the same thing and RCP8.5 may occur, for instance, if the carbon cycle responses are higher than the assumed in the integrated assessment models (IAMs)[4] as it appears to happen (IPCC, 2022; Schwalm et al., 2020). Schwalm et al. (2020) argued that "not only are the emissions consistent with RCP8.5 in close agreement with historical total cumulative CO_2 emissions (within 1%), but RCP8.5 is also the best match out to midcentury under current and stated policies with still highly plausible levels of CO_2 emissions in 2100".

1.3.2 The SSP Scenarios (Shared Socio-Economic Pathways)

SSP scenarios are partially inspired by the SRES (Nakicenovic and Swart, 2000a), like the RCPs. They comprise plausible reference trajectories for the evolution of society, detailing future socio-economic challenges, both for mitigation and adaptation to climate change, without considering

[3] The IPCC defines "unlikely" and "more likely than unlikely" as between 0-33% and 50-100% probability of occurrence, respectively.
[4] See Annex I for a description of the main IAM used for this purpose

climate policies or impacts (Kok et al., 2019; Kriegler et al., 2014; O'Neill et al., 2016, 2014; van Vuuren et al., 2014).

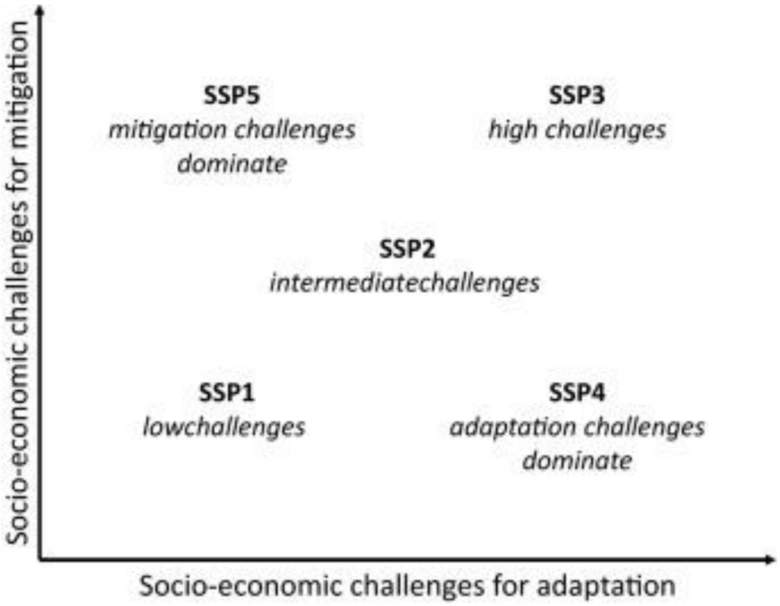


Figure 6. Schematic representation of SSP scenarios. Source: Riahi et al. (2017a)

These future alternative pathways reflect how the world might develop to reach a certain radiative forcing path (Richard H. Moss et al., 2010). Each SSP is described by a narrative, which consists of a simple story (Kok et al., 2019), that is, a qualitative description of future changes in demography, human development, economy and way of life, policies, institutions, technologies, and environmental resources (O'Neill et al., 2017). These narratives are the basis for creating GHG emissions and land use scenarios and are essential for analyzing the impacts, adaptation, and vulnerability (IAV) arising from climate change (O'Neill et al., 2017).

These scenarios describe five distinct ways the world could evolve without climate policies. The narratives include quantifications (e.g., population, GDP, land uses) obtained by integrated assessment models (IAM - Integrated Assessment Models). The range from a more sustainable world (SSP1) (van Vuuren et al., 2017) to a future World based on rapid fossil-fuel driven growth (SSP5) (Kriegler et al., 2017); a world with great inequality between countries or regions that result from the rise of nationalist movements and regional rivalries (SSP3) (Fujimori et al., 2017), a world with great inequality of investment in social capital between rich and poor countries (SSP4) (Calvin et al., 2017), and a world that maintains the observed historical trends of evolution (SSP2) (Fricko et al., 2017).

Table 1. Summary of SSP demographic and human development assumptions. LIC: Low-income countries, HIC: High-income countries, Conv.: conventional. Adapted from O'Neill et al. (2017b) and Dellink et al. (2017a)

Variable	SSP1	SSP2	SSP3	SSP4	SSP5
POPULATION					
Growth	Relatively low	Medium	Low OECD/ High remaining	Low OECD/ Relatively high remaining	relatively low
Fertility	Average OECD/Low remaining	Average	Low OECD/High remaining	Low OECD/Low-high remaining	OECD high/low remaining
Mortality	Low	Average	High	Average OECD/Middle-High remaining	Low
Migration	Average	Average	-	Average	High
URBANIZATION					
Level	High	Medium	Short	Medium OECD/High remaining	High
Type	well managed	historical trends	poorly managed	Varied between and inter-city	Better management; scattered occupation
HUMAN DEVELOPMENT					
Education	High	Average	Low	Average OECD/ Low-V.low remaining	High
Investment in health	High	Medium	Short	Low LIC, medium HIC	High
Access to health, water, sanitation	High	Medium	Short	Low LIC, medium HIC	High
Gender equality	High	Average	Low	Low LIC, average HIC	High
Equity	High	Average	Low	Average	High
Social cohesion	High	Average	Low	Low; stratified	High
Participatory society	High	Average	Low	Low	High
TOTAL FACTORS PRODUCTIVITY					
Growth	Medium	Medium	Short	Medium	High
Convergence Speed	High	Average	Low	Low PBR, average PER	High
Opening	Average	Average	Low	Low PBR, average PER	High
FOSSIL FUELS					
Sources	Conv: medium No Conv: low	Medium	Conv: medium No Conv: high	oil: low gas: high	Conv: medium No Conv: high
Price	Short	Medium	High	High	Oil: medium gas: low

1.3.2.1 SSP1 NARRATIVE: SUSTAINABILITY – GO GREEN

The world gradually changes towards a more sustainable path through a more inclusive development that respects environmental limits. These changes are driven by growing awareness and accountability for environmental degradation and inequalities and the social, cultural, and economic costs that come with it. The management of common goods is improved via greater collaboration and cooperation at all levels (local, national, international organizations/institutions, the private sector, and society). Investments in education and health accelerate the demographic transition, decreasing the population concerning current numbers. The main priority is no longer economic growth, and human well-being takes center stage, even if this change implies slower economic growth over time. Countries' internal and external inequalities decrease thanks to the commitment of achieving development goals. Investment in environmental technologies and changes in taxation structures increase resource efficiency, reducing energy and resource consumption and improving long-term environmental conditions. Renewables are becoming more popular, thanks to increased investments and financial incentives in this area and changes in perspective and awareness. Consumption focuses more on low material growth and lower resource and energy intensity.

The challenges for mitigation are relatively low due to the combination of developing more environmentally friendly technologies, good acceptance of renewable energies, relatively low energy demand, and institutions that facilitate international cooperation. The challenges for adaptation are also low, thanks to improvements in human well-being and robust and flexible institutions at the global, regional, and national levels.

1.3.2.2 SSP2 NARRATIVE: MIDDLE GROUND – KEEPING CURRENT TRENDS

The world follows a path in which social, economic, and technological trends do not undergo significant changes concerning historical trends. There is a heterogeneous growth and increase in income, with positively evolving countries and others falling short of expectations. Political stability is a reality in most economies. Global markets function imperfectly. Global and national institutions work to achieve sustainable development goals (improving living conditions and access to education, clean water, and health care), showing slow and gradual improvements. Technological development is evolving but without major advances. Despite reduced energy and resource consumption, environmental systems are degraded. Despite dependence on fossil fuels slowly decreasing, there is no reluctance to use other unconventional fossil fuels. Population growth is moderate and stabilizes in the second half of the century due to the demographic transition. However, investments in education are not enough to accelerate the transition to low fertility in low-income countries or rapidly slow population growth. This sustainable growth and income inequality that persists (or very slowly improves), continued social stratification, and limited social cohesion pose challenges in reducing vulnerability to social and environmental change and constrain significant progress towards development.

These development trends make the world face moderate challenges in terms of mitigation and adaptation, but with significant heterogeneity across and across countries.

1.3.2.3 SSP3 NARRATIVE: REGIONAL RIVALRY – A BUMPY ROAD

Countries are forced to focus more and more on local or, at best regional problems, primarily due to growing nationalism, concerns about competitiveness and security, and regional conflicts. This trend is supported by the limited number of comparatively weak global institutions, with uneven coordination and cooperation in dealing with the environment and other global issues. Policies change over time, being increasingly oriented towards national and regional security issues, including trade barriers, particularly regarding energy resources and agricultural markets. Countries focus on achieving energy and food security goals in their regions, and many regions move towards more authoritarian forms of government with highly regulated economies. There is a decrease in investments in education and technological development. Economic development is slow, and consumption is intensive. Inequalities persist or worsen over time, particularly in developing countries. There are areas of extreme poverty and areas of moderate wealth. Many countries have difficulties maintaining acceptable living standards and providing access to clean water, sanitation, and health care to the most disadvantaged populations. Some regions suffer severe environmental degradation due to the low international priority given to environmental issues. The combination of stagnant development with limited environmental concerns results in little progress towards sustainability. Population growth is low in developed countries and high in developing countries. There is an increasing intensity in the use of resources and dependence on fossil fuels, slow technological change, and difficulty securing international cooperation.

These factors imply high challenges concerning mitigation. Limited progress in human development, sluggish income growth, and a lack of competent institutions that can act across regions contribute to the heightened challenges to adaptation for many groups in all regions.

1.3.2.4 SSP4 NARRATIVE: INEQUALITY — A DIVIDED ROAD

Unequal investments in human capital and growing disparities in economic opportunity and political power lead to increasing inequalities and stratification within countries, both externally and internally. Over time, the distance between internationally connected societies with high levels of education, which contribute to sectors of the global economy with high involvement of knowledge and capital, widens; and societies with low levels of education, low incomes, where the economy is low-tech and labor-intensive. Power is more concentrated in a relatively small political and economic elite, even in democratic societies, while vulnerable groups are under-represented in national and global institutions. Economic growth is moderate in industrialized and middle-income countries. In contrast, low-income countries lag behind, often facing difficulties providing adequate access to water, sanitation, and health care for those most in need. Social cohesion worsens, and conflicts and problems become increasingly common. Technological developments are high in high-tech economies and sectors. Uncertainty regarding fossil fuel markets results in low investment in new resources in many world regions. Energy companies prevent price fluctuations in part by diversifying energy sources, investing not only in carbon-intensive fuels such as coal and unconventional oil but also in low-carbon energy sources. Environmental policies focus on specific issues in middle- and high-income locations.

The development of low-carbon options, the gain of experience in this area, and the well-integrated political and business classes at the international level and capable of rapid and decisive action result in low challenges for mitigation. Concerning adaptation, the challenges are high, as a substantial proportion of the population is at a low level of development and has limited access to institutions that allow them to deal with economic or environmental stresses.

1.3.2.5 SSP5 NARRATIVE: FOSSIL FUEL-BASED DEVELOPMENT – TRAVELING THE FREEWAY

Thanks to the success of industrialized and rising economies, there is an increase in confidence in competitive markets, innovation, and participatory societies for technological progress and the evolution of human capital with a view to sustainable development. Global markets are increasingly integrated and focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also substantial investments in health, education, and institutions to improve human and social capital. Furthermore, the drive for economic and social development is linked to the abundant exploitation of fossil resources and the adoption of lifestyles related to the intensive use of resources and energy worldwide. These factors lead to the rapid growth of the global economy. Confidence in managing social and ecological systems is high, using geoengineering techniques whenever necessary. Environmental impacts at the local level are mitigated thanks to technological solutions. However, the effort to avoid global environmental impacts is small due to the idea that this effort would imply a decrease in economic progress/development. The global population peaks around 2055 and begins to decline during the 21st century. Although fertility declines rapidly in developing countries, developed countries have relatively high fertility rates (at or above the replacement rate) due to more optimistic economic prospects. Due to the gradual opening of labor markets, international mobility increases as the pay gap narrows.

Heavy reliance on fossil fuels and lack of environmental concern result in potentially high challenges for mitigation. The fact that the economy is robust, human development goals are met, and infrastructure is carefully planned using engineering results in relatively low challenges for adapting to any effects of climate change.

1.3.3 The SPA climate policy scenarios (Shared climate policy Assumptions)

As mentioned above, the SSPs do not consider, in their formulation, future climate policies or impacts. However, they contain the climate policies adopted by countries when creating the SSP or the date of their application in an integrated assessment model (IAM) and numerous non-climate related policies (Hausfather, 2018). According to van Vuuren et al. (2014), this option consists of a methodological choice that SSPs facilitated as reference cases for considerations related to mitigation or climate impacts (Riahi et al., 2017). These SSPs, without climate policies, are called baseline scenarios (Figure 7).

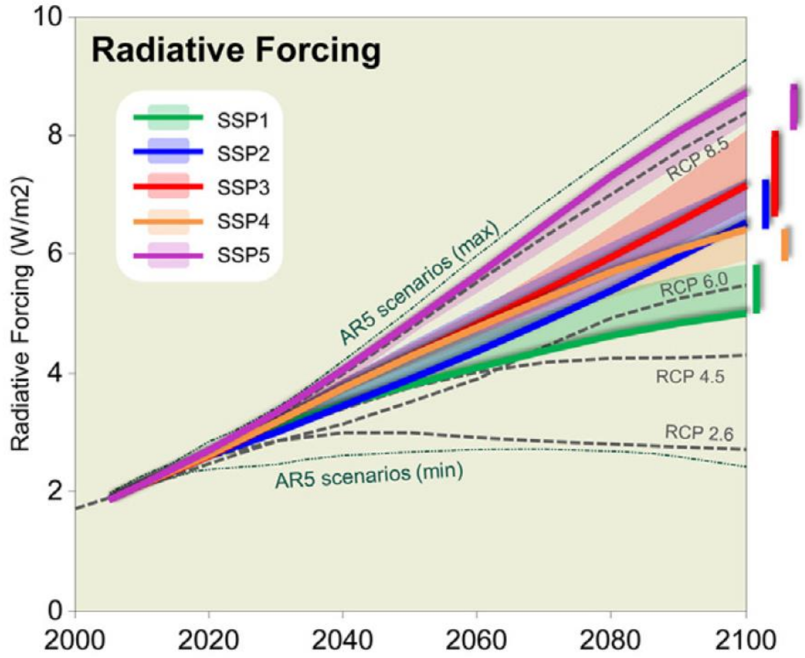


Figure 7. Comparison chart between CPR and SSP scenarios. This graph does not take climate policies into account. It should be noted that "to achieve radiative forcing levels below 6 W/m^2, it is necessary to consider climate change mitigation policies". Source: Riahi et al. (2017)

The non-incorporation of climate policies implies that the baseline of the different SSP scenarios results in radiative forcings between 6.0 and 8.5 W/m 2 at the end of the 21st century. However, it is possible to apply these scenarios to achieve different radiative forcings. This application depends on the implementation of climate policies, both global and local, throughout the century and on the various configurations of how the mitigation objectives can be achieved (Riahi et al., 2017).

This compatibility is achieved with the use of Shared climate policy Assumptions (SPA) or climate policy assumptions, which consist of the key features of climate change mitigation and adaptation policies, considering policies up to the global scale and up to the end of the century (Kriegler et al., 2014). SPAs do not necessarily consider all the details of climate policy, essentially focusing on the relevant policy assumptions (Kriegler et al., 2014).

Like SSPs, SPAs include both quantitative and qualitative (narrative) aspects. The narratives contain information on the different temporal moments in which regions and nations may jointly participate in efforts to reduce greenhouse gas emissions, also describing the commitment to mitigating climate change in the regions or countries participating in these efforts. These also include the nature of climate policies (preference for fiscal policies or regulatory policies), the extent to which mitigation efforts are directed towards fossil fuels or land uses, or whether policies focus on the demand side (e.g., behavioral changes, efficiency) or more supply-oriented solutions, such as low-emission technological development (Kriegler et al., 2014).

The SPA narratives include information on institutional policies to support adaptation on the adaptation side. For example, the implementation of international technology transfer agreements, governance aspects related to quality, the capacity to implement adaptation measures (which can be weakened, e.g., by corruption or conflicts of interest), and how effective policies are implemented.

By incorporating climate policies, the compatibility of different SSP-RCP combinations becomes feasible. These combinations have been studied and quantified, in the last decade, using integrated assessment models (IAM). They made it possible to define combinations in which this compatibilization is possible and others in which this is not possible, as the internal structure (storylines) of the SSP is no longer coherent (Figure 8).

	SSP1	**SSP2**	**SSP3**	**SSP4**	**SSP5**
RCP2.6	**X**	**X**		**X**	**X**
RCP4.5	**X**	**X**	**X**	**X**	**X**
RCP6.0	**X**	**X**	**X**	**X**	**X**
RCP8.5					**X**

Figure 8. Structure of SSP-RCP scenarios possible without loss of coherence of SSP storylines. The most charged tones are marked SSP1 and five baselines

In this way, there are:

- the RCPs, expressing four radiative forcing trajectories[5];

[5] In the sixth IPCC report, published in late 2021, the radiative forcings 1.9, 2.6, 3.4, 4.5, 6.0, 7.0, and 8.5 were studied. As described by O'Neill et al. (2016), the AR6 radiative forcings are coupled to the socioeconomic scenarios in the following combinations: SSP5-8.5, SSP3-7.0, SSP2-4.5, SSP1-2.6, SSP4-6.0, SSP4-3.4, SSP5-3.4-OS, SSPa-b (forcing less than 2.0).

- the SSPs describe and quantify five future worlds with different levels of societal development, not integrating climate policies (O'Neill et al., 2017b; Riahi et al., 2017); and
- the SPAs describe mitigation and adaptation policies and the level of international cooperation to address climate challenges (Kriegler et al., 2014; van Vuuren and Carter, 2014).

1.3.4 The climate and socio-economic scenarios of the sixth IPCC report

In 2006, the scientific community started defining new socio-economic scenarios to replace the SRES[6], scenarios published within the IPCC through the Special Report on Emissions scenarios (IPCC, 2000; Nakicenovic and Swart, 2000a)[7].

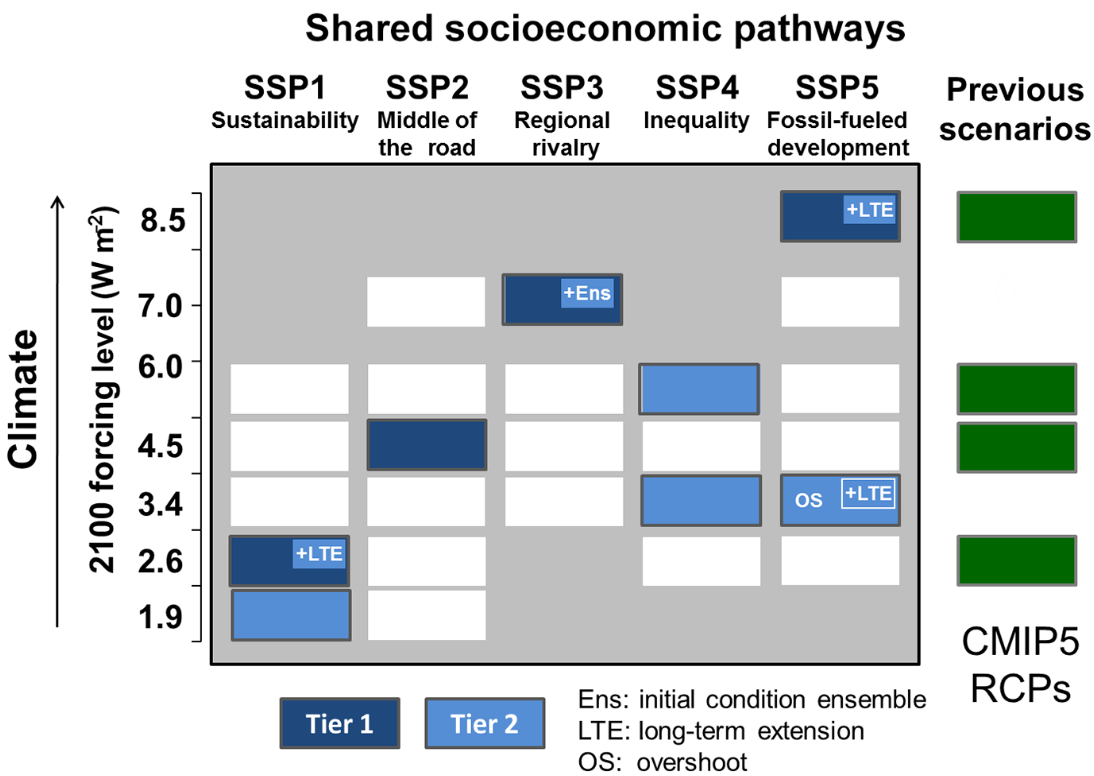


Figure 9. Scenarios under development within the framework of the sixth IPCC report. In this image, two priority levels are identified to prepare projections (level 1 and level 2). Some characteristics of each scenario are specified, namely, those that will have a temporal extension of the projections until 2300 (SSP1-2.68, SSP5-3.4, and SSP5 -8.5), the one in which the internal variability of the models will be evaluated, concerning the results in different runs in the output variables obtained (SSP3-7.0) and projections for the SSP5-3.4 called overshoot, since the emissions are identical to SSP5-8.5 by 2040, followed by a drastic decrease in these same emissions (see also Figure 10). Source: adapted from O'Neill et al. (2016).

[6] See Annex III for more information on the different scenarios used within the different IPCC reports.
[7] For more information, see Annex II
[8] SSP1-1.9 provides the lowest estimate of future radiative forcing, consistent with the most ambitious goals of the Paris Agreement (which recommend undertaking efforts to limit the global average temperature increase to 1.5°C above pre-industrial values). SSP1-2.6 represents efforts to limit the global average temperature increase to 2°C above pre-industrial levels (1850-1900).

This new generation of socio-economic scenarios had the following objectives, which have since been achieved: i) to update the trends in greenhouse gas emissions, ii) to be useful both for mitigation and for the adaptation/assessment of impacts through the greater scope, iii) to consider climate policies, something that SRES scenarios do not consider, iv) to respond to detailed information needs for new climate models, namely aerosol emissions, geographically explicit descriptions of land use and its emissions as well as detailed specifications of emissions by type of source; v) to respond to the need for closer collaboration between the different disciplines involved in the formulation and use of climate scenarios, allowing for the consistent use of scenarios for different objectives and modeling methods; and vi) assessing the "costs" and "benefits" of long-term climate goals (Richard H. Moss et al., 2010; van Vuuren et al., 2012a, 2012b, 2011a).

The creation of the new socio-economic scenarios (SSP) took place in parallel with the definition of climate scenarios (RCP) to reduce the time required for the implementation of a sequential methodology and to encourage interactions between the scientific community (Moss et al., 2010). In this way, while the climate modeling teams dealt with the RCPs and associated simulations, the new socio-economic and emission scenarios were being developed by the modeling teams through the application of IAM (Richard H. Moss et al., 2010; van Vuuren et al., 2014). Via this modeling and the SPA integration, it was possible to make the RCP compatible with the SSP, as mentioned above (Figure 8). Thus, making it possible to publish numerous studies and new scientific knowledge with applicability in different contexts, such as modeling and evaluation of impacts and vulnerabilities to climate change, land use projections, or economic assessment of adaptation costs (Doelman et al., 2018; Kebede et al., 2018; Koutroulis et al., 2019; Liao et al., 2020; Popp et al., 2017a; Riahi et al., 2017b; Tamura et al., 2019).

O'Neill et al. (2016) outlined the SSP-RCP combinations to be developed for the sixth assessment report (AR6) of the IPCC (Figure 9).

According to Gidden et al. (2019b), the SSP-RCP[9] framework proposed in 2016 provides two key elements for scenario development:

i) standardizes all socio-economic assumptions (e.g., population, gross domestic product, and poverty, among others) in all modeling that seek to represent each scenario;
ii) allows for a more nuanced inquiry into the various ways climate goals can be achieved.

[9] Implying the use of SPA.

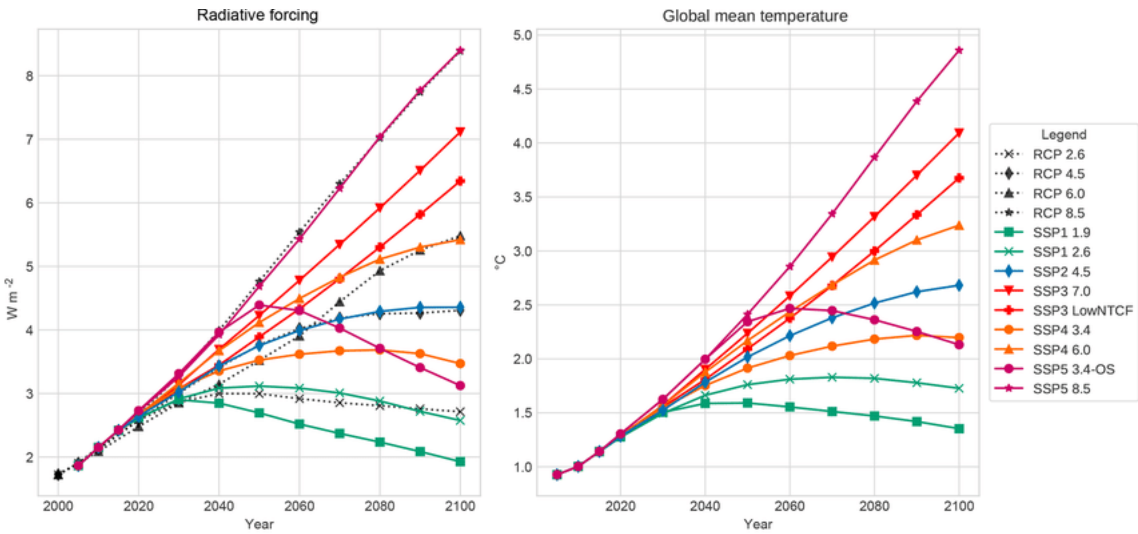


Figure 10. Radiative forcing and global mean temperature in the different SSP-RCP scenarios under development for the sixth IPCC report. Source: adapted from Gidden et al. (2019b)

1.4 Other international sources of socio-economic projections for Portugal

Multiple international sources produce socio-economic projections that include disaggregated information for Portugal. These differ from SSP scenarios in the assumptions adopted, which normally project the future considering past developments. While the objective is not to carry out an exhaustive survey of these sources, there are 3 of relevance in the context of this report:

i) The United Nations, which has population projections up to 2100, a time horizon that coincides with the RNA2100 project;

ii) The Organization for Economic Co-operation and Development which provides economic projections with a medium-term time horizon; and

iii) The "Ageing Report" for being used within the scope of the PESETA IV project," Projection of economic impacts of climate change in Sectors of the European Union based on bottom-up analysis, "which has similar goals to the RNA2100 project

The United Nations (UN) Department of Economic and Social Affairs publishes population projections up to 2100, disaggregated by country, including Portugal. These projections use the Cohort component method (UN, 1956). They are based on data since 1950 from different official sources of information, namely population census data, birth and mortality records, HIV prevalence, infant mortality, or migration statistics. Future projections in the demographic components of fertility and mortality are obtained through probabilistic methods derived from historical observations, allowing the creation of different variants of future evolution. The values normally presented correspond to the median of the results obtained, with the last projections made in 2019 (UN, 2019).

The Organization for Economic Co-operation and Development (OECD) provides economic projections (Gross Domestic Product) until 2060.

The Directorate-General for Economic and Financial Affairs of the European Commission (EC) periodically publishes long-term socio-economic projections for all member states, called the "Ageing Report" (EC, 2021). In its current version, different socio-economic data are available until 2070. The demographic variables are based on population projections developed by Eurostat, which currently provides population data up to 2100, disaggregated by the NUTS III region.

1.5 National sources of socio-economic projections

The sources of socio-economic information in Portugal for long-term projections consist only of the demographic projections for Portugal, published by the National Institute of Statistics (INE). The methodological basis was like the method used by the United Nations Population Department (UNPD), using the same Cohorts approach. However, the results may differ from the United Nations data. This is because the future levels of the components of demographic variation - fertility, mortality, and migrations - rely on the opinion of experts regarding their future evolution. However, they integrate analysis and modeling of the past trends, like the projections made by the United Nations.

Although demographic projections are only available until 2080, this information source has the advantage of disaggregating information by NUTS II.

2. Methodology

This chapter presents the state-of-the-art methodologies for socio-economic projections/scenarios. It has as its fundamental objective the definition of demographic and economic indicators to be used in the RNA2100 project and for mainland Portugal. The report analyzes the SSPs for Portugal, their use for Portugal, and other relevant sources of information, aiming to build socio-economic scenarios for Portugal. We present projections of Portugal's land use and global greenhouse gases converted into carbon dioxide equivalent (CO_2e) are presented.

In the first phase, the approach analyzes the SSP-RCP scenario combinations. These are described above for mainland Portugal. Among the possible SSP-RCP combinations (developed in priority level 1 within the scope of the sixth IPCC reports (AR6)) (see Figure 9 & Figure 10).

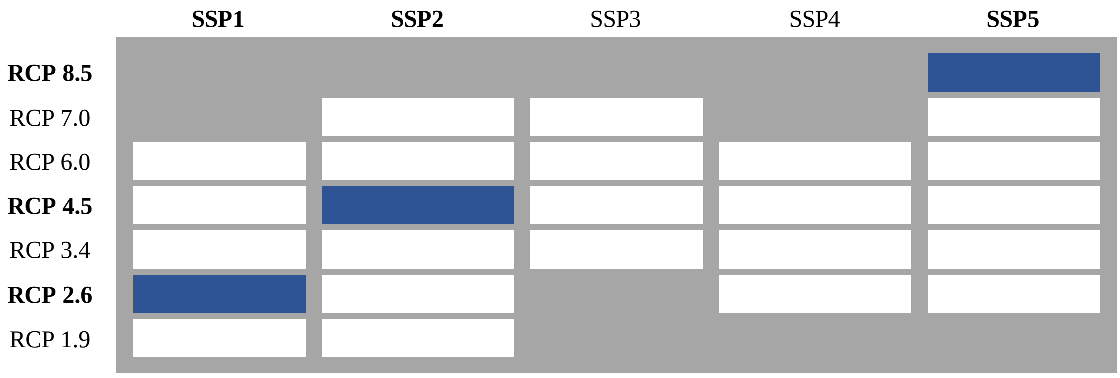


Figure 11. Matrix of possible SSP-CPR combinations, highlighting the combinations considered within the scope of this study (dark blue)

The multiplicity of published studies provides robust information for the same combinations within the scope of the previous phase of the referred project (CMIP5). This information, combined with scientific publications already developed within the scope of CMIP6, allows for a stable approach aligned with international assessments, producing new knowledge for Portugal.

In a second phase, the combination of SSP-RCP scenarios and other sources that could be used in a medium/long-term adaptation planning exercise were analyzed, concerning similar studies carried out at the European level. PESETA IV uses other sources of information to define socio-economic scenarios.

2.1 Greenhouse gas projections in the various SSPs and SSP-RCPs

The carbon dioxide equivalent (CO_2e) represents all greenhouse gases through a single indicator, which results from converting these gases into carbon dioxide. A given group of greenhouse gases (different substances and amounts) describes the amount of CO_2 that would have the same global warming capacity as the atmosphere in a specified period, usually set to 20, 50, or 100 years (IPCC, 2013).

The representation of all greenhouse gases through CO_2e was followed in the Roadmap for Carbon Neutrality 2050 (APA, 2012) but is not compatible with the information made available for the SSP, which, due to its objectives, has all greenhouse gases inventoried separately for each scenario (Riahi et al., 2017a) In this sense, it was considered necessary to convert the greenhouse gases published by Riahi et al. (2017a) and made available on the SSP Database in CO_2e. This conversion is done worldwide since the resulting impacts from climate change depend on global emissions regardless of the individual efforts of each country.

The composition of gases comprising CO_2e, and their calculations varies between studies. This study's CO_2e calculation was based on the GHGs listed in Annex A of the Kyoto Protocol (UN, 1997). This option allows the comparability of results with other studies due to its broad scope, e.g., the emission gap reports published annually by the United Nations Environmental Program (UNEP). In line with these reports, the global warming potential (GWP) period was considered 100 years (e.g., UNEP, 2019). Table 2 presents the used equivalence of the global warming potential (GWP) between the different greenhouse gases and CO_2.

Table 2. Greenhouse gases defined in the Kyoto protocol, comparable gases in the SSP database, and equivalence between these gases and CO_2 according to IPCC (2013), used for the conversion of greenhouse gases into CO_2e

Kyoto Protocol's definition of greenhouse gases		**Definition in the *SSP database***	**GWP (100 years)**	**Conversion to CO_2 and the SSP *database***	**GWP Conversion Source 100 years**
Carbon dioxide	CO_2	CO_2	1	NA	IPCC (2013), Table 8.7
Methane	CH_4	CH_4	28	No	IPCC (2013), Table 8.7
Nitrous oxide	N_2O	N_2O	265	No	IPCC (2013), Table 8.7
hydrofluorocarbons	(HFCs)	HFC-134a	1300	Yes	IPCC (2013), Table 8.7
perfluorocarbons	(PFCs)	CF_4	6630	No	IPCC (2013), Table 8.7
sulfur hexafluoride	SF_6	SF_6	23500	No	IPCC (2013), Table 8.A.1

2.2 Demographic Projections for Portugal

The demographic projections for Portugal result from the collection and processing of data to allow comparability between sources of information and approaches. Here, the comparison with the Roadmap for Carbon Neutrality 2050 is one of the objectives of this report. As mentioned above, data from the SSP scenarios, other international sources of information, namely the United Nations Department of Economic and Social Affairs and Eurostat, and national information sources, which consisted of the projections prepared by INE.

2.2.1 Demographic Projections Considering SSP

The Portuguese SSP population data were extracted from the SSP Database. The SSP population data were generated through multidimensional mathematical modeling (KC and Lutz, 2017). The information is available between 2010 and 2100, every five years.

The SSP data was analyzed and compared with INE information for 2010, which is the base year for the projections of the different SSPs. Deviations were identified between the base year and the information provided by INE due to the correction made to the series by the same institution after each census moment. More specifically, the year 2010 of the SSP Database consists of the provisional value for 2010 made available by INE (and reported by the latter to different institutions), but before the corrections made after the 2011 Census for that year (turning to the absolute value), which implies a difference in the total Portuguese population of around 100,000 inhabitants.

In this context, and to correct the information, the 2010 value was updated to match the census period assumed. From this, ratios calculated between the population value of year x and the value of 2010, originating in the SSP Database, were applied.

The SSP Database also provides information on the population for Portugal by age group, with systematic differences between the sum of the different age groups in a given year and the total population for that same year.

To make the information coherent, the proportions of each age group were calculated concerning the total population in each year. These proportions were applied to the total population for Portugal, previously corrected with the definitive data from the INE's 2010 population.

The corrections made considered the total population and the division by sex, following the same procedures as those explained for the total population.

All corrections made make it possible to directly compare the projected results until the end of the century and the historical population data for Portugal.

In this context, graphs were also calculated and generated between 2010-and 2100, considering the different SSP for the total dependency index and the aging index, and age pyramids were also created.

2.2.1.1 Demographic Projections for the Nuts II Regions of Mainland Portugal

Demographic projections by region were based on work done by Jones & O'Neill (Jones and O'Neill, 2016), who regionalized the population at a global level to a grid with a resolution of 0.5

° and 2.5', covering the years 2006 to 2100 and based on the SSP Database projections for the five SSP. The authors refer that the regionalization of the total population is not equal to the base values due to the simplified interpolation method used (linear interpolation of decadal population data). However, the differences are less than 0.01%, which is considered an acceptable error for country-level analyses. This publication also mentions that the grid cells containing borders encompass multiple countries' populations. The information produced by these authors is made available within the scope of the "Inter-Sectoral Impact Model Intercomparison Project".[10]

The methodology applied to correct and obtain the population disaggregated by regions sought to correct the errors identified while making the grid information compatible with the geographic limits of the NUTS II regions of mainland Portugal.

In this sense, the first step of the analysis consisted of the aggregation of existing information in cells adjacent to the coastline since there are grid cells that are geographically not coincident with land but have population values greater than zero. Normally residual values were assigned to the cell with the closest shoreline (see Figure 12).

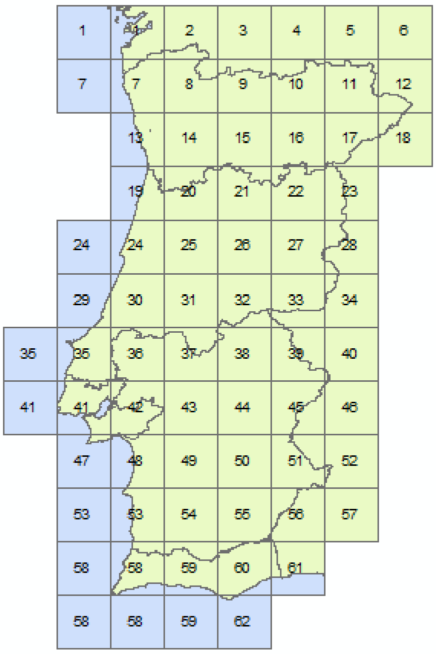


Figure 12. Annual global population data grid superimposed with the NUTS II regions of Portugal. The values of each cell entirely located in the ocean were added to the closest cell on land with the same numbering (see example: cell 53).

The basis for comparison with current data consisted of census data from Portugal and Spain for 2011. The border cells contain data from both countries, using the information at the level of statistical subsections.

[10] https://esg.pik-potsdam.de/search/isimip/

The resident population in each statistical subsection contained within the limits of each cell of the Annual global population data grid created by Jones & O'Neill (Jones and O'Neill, 2016) was aggregated as follows:

- If a grid cell covers more than one region, the values were summed separately (two or more values in the same cell) to maintain the limits of the regions, with Spain being considered as a single region for this end;
- If a statistical subsection is contained in two or more cells, the population value has been proportionally divided by the area of the subsection that lies in each of those cells;
- Finally, the sum of the values obtained in 1. and 2. in each cell or part of a cell was performed to consider the regions' borders.

This first procedure made it possible to create a grid-based on the 2011 Census, with the same size as the Annual global population data grid and containing the limit of each NUTS II region (see Figure 13). This procedure made it possible to identify and correct existing deviations between the 2011 Census data and the grid that contains population projections until the end of this century in the different SSP scenarios.

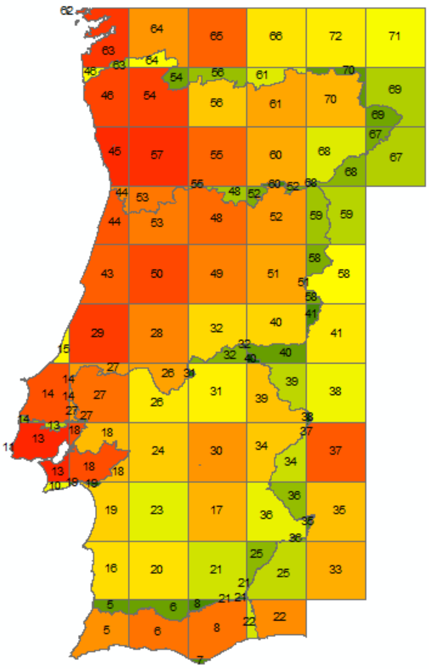


Figure 13. Result of transforming the 2011 Census subsections into a grid that coincides with the Annual global population data, maintaining the limits of the NUTS II regions. Warm colors refer to a higher number of the resident population, and cool colors to lower values.

Once these deviations were detected, they were corrected based on the 2011 Census, applying the trends identified in the Annual global population data grid to these. The methodology consisted of:

- When a cell of the Annual global population data grid is allocated to a single region, the anomaly in the population between the year 2011 and year x of the cell was calculated, followed by its application to the geographically coincident cell obtained by aggregating data from the 2011 Census;
- When a cell of the Annual global population data grid covers more than one region, the anomaly was applied as described in 1. The value obtained was proportionally divided, considering each region's total resident population in 2011.

This operation maintained the existing differences between the data from the Annual global population data grid and the total population for Portugal originating in the SSP Database, which are reflected in the totals for each region. To make both information compatible, the distribution of the missing population was applied proportionally by the different cells/parts of the cell, considering the number of inhabitants in 2011 of each cell/part of the cell for this purpose. This operation was carried out considering the population residing in the autonomous regions of the Annual global population data grid since the SSP Database data refer to Portugal. However, the results presented are only for the NUTS II regions of the continent.

2.2.2 Demographic Projections from International Sources

Two international information sources were considered in the context of demographic projections for Portugal and studied their best applicability to the RNA2100 project. These consist of those produced by the United Nations Department of Economic and Social Affairs (UN, 2019) and by the Eurostat (Eurostat, 2020).

The information produced by the United Nations uses the method of components by Cohort, projecting the components of demographic dynamics (fertility, mortality, and net migration) separately for each birth cohort (people born in a given year). Each year, the base population is modified using projected survival rates and net international migrations.

Since these projections are carried out for 235 countries or regions, the total population and the components of population dynamics differ. These concern the analysis period and the quality of information, with some of these data being estimated (UN, 2019).

Projections are available until 2100, including a low, medium, and high variant, based on assumptions including fertility, mortality, and international migration (see UN (2019)).

The data used in the report's analysis consists of the medium, low, and high variants, compared with information from the INE for the year 2020, which is the base year for the projections made by the Department of Economic Affairs and Social Affairs of the United Nations. Here, we identified minor deviations, but these are not significant. Thus, we used the data without modifications.

Regarding the information produced by Eurostat, the most recent version was published in 2020 and provides a baseline projection up to 2100 and five variants that result from sensitivity tests for the dynamic components (fertility, mortality, and net migration). The baseline projection is broken down to NUTS III regions. It has as its primary assumption that the socio-economic differences of the European Union member states will fade in the very long term, which is therefore based on a partial convergence in each of the components of demographic (Eurostat, 2020).

The data used in the analysis carried out within the scope of this report consisted of Eurostat's base projection, having been compared with information from INE for the year 2020. Eurostat's projection begins in 2019, with a small deviation in the following year compared with INE information. However, these deviations are not significant and do not compromise the comparability of trends between studies, so no changes were made.

2.2.3 Demographic Projections from The National Institute of Statistics

The National Statistics Institute periodically publishes resident population projections for Portugal and the respective NUTS II. The current version was completed in 2020, comprising the analysis period from 2018-to 2080, using the cohort component method (INE, 2020a). The formulation of hypotheses about the future evolution of the population variation components results from different statistical modeling approaches that integrate the past evolution of these components, allowing their extrapolation and subsequent subjective evaluation of the results through expert judgment.

The combination of different alternative hypotheses regarding the future evolution of each component allowed the definition of population projection scenarios. In particular, four scenarios are defined for Portugal and NUTS II regions (INE, 2017a):

i. Low Scenario: In this scenario, the pessimistic hypotheses for fertility, central for mortality, and pessimistic for migrations are considered.
ii. Central Scenario: In this scenario, the hypotheses of central fertility evolution, central mortality, and central migrations are considered.

iii. High Scenario: This scenario results from the combination of the assumptions of an optimistic evolution of fertility, optimistic mortality, and an optimistic migration.

iv. Scenario without migrations: Finally, a scenario equal to the central scenario but without migrations.

Of these four scenarios, the first three are explored in more detail, within the scope of this report, excluding the scenario without migration, as it is a scenario with solid improbability (INE, 2017a).

2.3 Gross Domestic Product Projections for Portugal

There are fewer existing sources of information for economic variables when the objective is to identify medium and long-term trends. However, two international information sources were identified that produce long-term projections. The first is related to the narratives of the SSPs, being prepared by the OECD, and the other is carried out by the Directorate-General for Economic and Financial Affairs of the European Union and published within the scope of the Ageing report (EC, 2021).

2.3.1 GDP Projections Based on SSP Narratives

The Gross Domestic Product (GDP) data for Portugal in each SSP is based on work by Dellink et al. (2017b), which is being made available on the SSP Database. This database provides two different projections for Portugal, being chosen the projection developed by the OECD, whose methodology and results are described in detail in Dellink et al. (2017b).

The information collected comprises GDP values for Portugal (between 2010 and 2100, every five years) in 2005 Purchasing Power Parity (PPP), the currency being the US dollar. Currency conversions used in each country for the GDP calculation, made available by the SSP Database, consisted of the exchange rates from the World Bank's International Comparison Program (Dellink et al., 2017b).

To avoid using exchange rates or purchasing power parity relative to other years, we decided to calculate the GDP Variation Percentage based on 2015 and the Annual Average GDP Variation Rate based on the original indicators. This approach avoids difficulties arising from the conversion of GDP to other units while allowing comparison with other projections, namely those of the Roadmap for Carbon Neutrality 2050.

2.3.2 GDP Projections from International Sources

International sources of information that project medium and long-term GDP are relatively scarce. However, the European Union Department of Economic and Social Affairs provides projections of GDP growth rates up to 2070 for each EU member state. These projections integrate Eurostat's demographic projections regarding the active population at a given time and use a Cobb-Douglas production function (Cobb and Douglas, 1928) as a base methodology (EC, 2020).

In this sense, in this context, GDP projections for Portugal result from the collection of information published within the scope of the Ageing report (EC, 2021).

2.4 Land use projections for Portugal

Land use changes represent one of the most critical human effects on human induced climate change and a crucial area regarding climate change adaptation (IPCC, 2022c, 2022b). Hence, the growing number of publications focus on projections of these changes, considering the different SSPs. The reference database in this field for climate change models is Land Use Harmonization dataset, which provides information on land use changes in a 0.25 ° by 0.25 ° grid, comprising a variable time scale, covering different periods between the years 850 and 2300 (Hurtt et al., 2020, 2011). The most recent publication of this dataset projects land use changes, considering the SSP-RCP framework proposed in 2016 by O'Neill et al. (2016) through IAM models (for more information, see Figure 9 and Annex I).

A similar approach was followed by Chen et al. (2020). The authors projected land use changes until the end of the century, every five years, for all possible combinations between SSP and RCP (see Figure 8), and with a spatial resolution of 0.05 by 0.05°. This data set was chosen for the land use projections of Portugal and Spain within the scope of RNA2100. Table 3 presents the SSP land use narratives.

Table 3. Overview of land use narratives for the 5 SSP scenarios. Source: Popp et al. (2017b)

Tema	SSP1	SSP2	SSP3	SSP4	SSP5
Regulation of land use changes	Strong regulation to avoid trade-offs environmental	Medium regulation; slow decline in the rate of deforestation	Limited regulation; maintenance of deforestation	Strong regulation in high/ middle-income countries. Lack of regulation in low-income countries implies a high rate of deforestation	Medium regulation; slow decline in the rate of deforestation
Growth in soil productivity	High improvements in agricultural productivity; rapid dissemination of best practices	Moderate pace in technology changes	Low technological development	High productivity for large scale farming industry and low for small scale farming	Intensive management and high consumption of resources; rapid increase in productivity

Tema	SSP1	SSP2	SSP3	SSP4	SSP5
Environmental impact of food consumption	Low growth in food consumption, low meat-based diet	Intensive consumption of materials and moderate consumption of meat	Intensive consumption of resources	Elites: Consumption-based lifestyles. Others: low consumption	Intensive consumption of materials and a diet based on meat consumption
International trade	Moderate	Moderate	heavily conditioned	Moderate	Elevated and accompanied by regional production specialization
Globalization	Linked markets, but production is regional	Globalized and semi-open economy	Decline of the globalized economy. regional security	Globally Connected Elites	Strongly globalized world
Soil-based mitigation policies	Immediate international cooperation to mitigate climate change. Full participation of sectors related to land uses.	Delay in international cooperation to mitigate climate change. Partial participation of sectors related to land uses.	Strong delay in international cooperation to mitigate climate change. Limited participation of sectors related to land uses.	Immediate international cooperation to mitigate climate change. Partial participation of sectors related to land uses.	Delay in international cooperation to mitigate climate change.

The land use projections prepared by Chen et al. (2020) incorporate projections from five global climate change models (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC5, and NorESM -M) for each of the 15 SSP-RCP combinations. This methodological option resulted in 5 runs of the IAM[11] model for each combination, and it allowed an ensemble of results (average), whose global result is shown in Figure 14.

The land use projections within the scope of RNA2100 consider the cells for Portugal and Spain in this database. They result from the analysis of the ensemble results of the models in the SSP1-RCP2.6, SSP2-RCP4.5, and SSP5-RCP8 scenarios. 5. More specifically, each cell in the grid contains percentages of land uses. These percentages were converted into areas, considering the size of each cell. After this conversion, the values geographically coincident with Portugal and Spain for the 37 available classes database were added together. Table 6 presents the 37 classes. After this operation, the projected percentage changes in each SSP-RCP combination mentioned above were calculated, taking 2015 as a starting point. It remains to be noted that the analysis covered Portugal and Spain. This is because the territorial expression of some classes was not consistent with observed data. However, the values obtained through this approach make it possible to overcome this difficulty, representing a global trend of land use changes for both countries.

[11] The model used was the Global Change Assessment Model (GCAM).

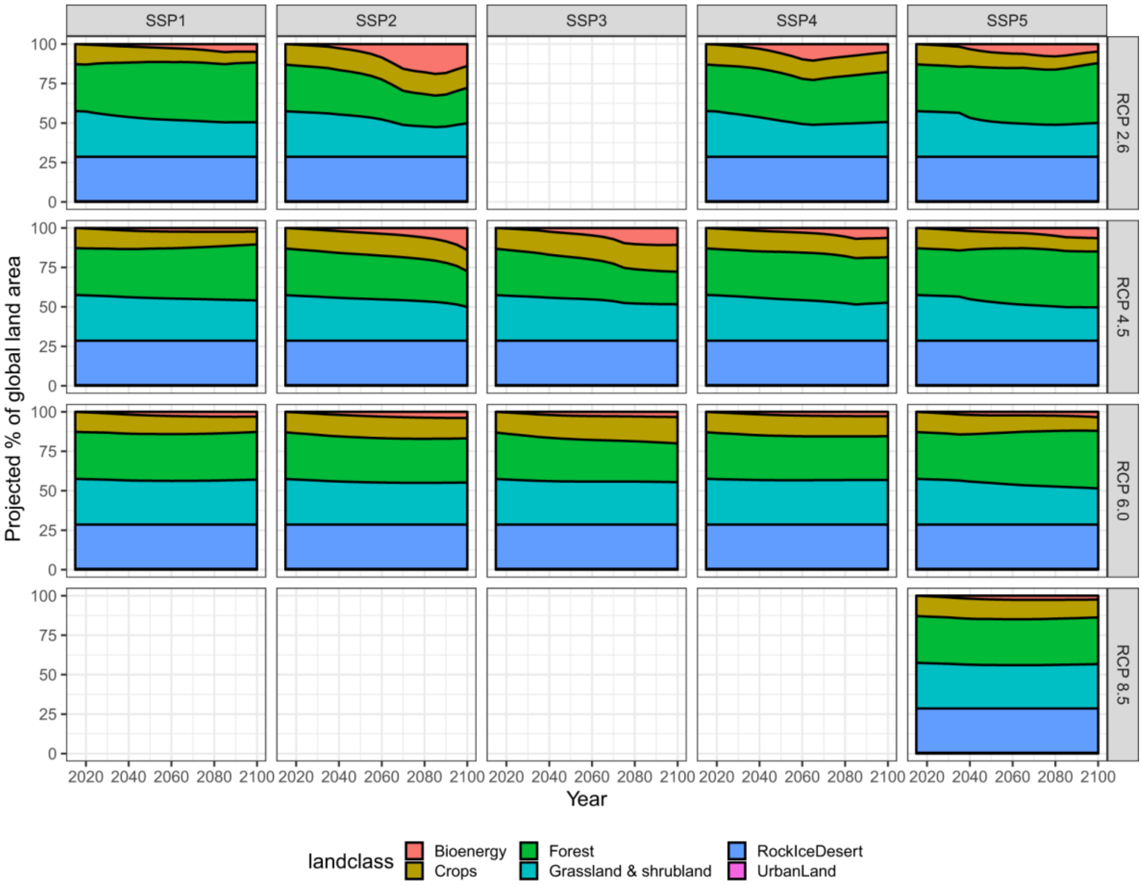


Figure 14. There are changes in land use at a global level and until the end of the century, considering the 15 SSP-RCP combinations. Large classes group land uses to improve the reading of the results. Source: Chen et al. (2020)

Projections of the urbanization rate for Portugal result from work published by Jiang & O'Neill (2017) and made available on the SSP Database. The indicator used for this purpose is the percentage of the population residing in urban areas.

2.5 Comparison of results with the Roadmap for Carbon Neutrality (RNC2050)

The comparison of results between the socio-economic projections considered in this document and the socio-economic and land use projections of the RNC2050 are presented in section 3.4. Table 4 summarizes socio-economic variables available within the scope of the RNC 2050 and those obtained through the different sources of information consulted.

Table 4. Socio-economic variables analyzed in RNC2050 (3 scenarios) and obtained within the scope of this report.

Variable	RNC 2050	SSPS	Other International Sources	National Sources
Resident population	Yes	Yes (And by NUTS II)	Yes (And by NUTS III)	Yes (And by NUTS II)
Population growth rate	Yes	Yes	Yes	Yes
total dependency index	Yes	Yes	Yes	Yes
aging index	Yes	Yes	Yes	Yes
Urbanization rate - households > 2000p	Yes	Yes (percentage of population residing in urban areas)	No	No
Urbanization rate - aggregates 10,000 > x > 2000p	Yes			
Urbanization rate - households > 10,000p	Yes			
Average size of private households	Yes	No	No	No
Average annual rate of change of GDP	Yes	Yes	Yes	No (to be developed by BDP)
Average annual rate of change of GDP per capita	Yes	Yes	Yes	
VAB Structure - Tradable VAB Ratio	Yes	No	No	
VAB Structure - Non-Tradable VAB Ratio	Yes	No	No	
Degree of openness to the outside	Yes	Yes (included in narratives)	No	
Average annual rate of change of income and consumption variables	Yes	No	No	

Regarding land uses, Table 5 presents the thirteen classes of land use and the two scenarios studied in this context in RNC2050. Table 6 presents twenty-six land use classes designed for the three SSP-RCP scenarios, which can be applied in RNA2100.

Table 5. Land use classes presented within the scope of RNC2050

Classes	Pelotão	Camisola Amarela	Fora de Pista
soils with forests	X	X	
maritime pine	X	X	
cork oak	X	X	
Eucalyptus	X	X	
holm oak	X	X	
oaks	X	X	
other hardwoods	X	X	
stone pine	X	X	
other softwoods	X	X	
soils with agriculture	X	X	
Soils with pastures	X	X	
Soils with flooded areas	X	X	
Urbanized land	X	X	
Soils with weeds and other uses	X	X	

Table 6. Classes of land use subject to integration within the scope of RNA2100. In shades of gray are the classes for which there is no representation in the Iberian Peninsula

Code	classes	SSP1-2.6	SSP2-4.5	SSP5-8.5
PFT0	Water	x	x	x
PFT1	Evergreen needle-leaf trees: temperate	x	x	x
PFT2	Evergreen needle-leaf trees: boreal	x	x	x
PFT3	Needle-leaf deciduous trees: boreal			
PFT4	Broadleaf evergreen trees: tropical			
PFT5	Broadleaf evergreens: temperate			
PFT6	Broadleaf deciduous trees: tropical			
PFT7	Broadleaf deciduous trees: temperate	x	x	x
PFT8	Broadleaf deciduous trees: boreal	x	x	x
PFT9	Broadleaf evergreen shrubs: temperate	x	x	x
PFT10	Broadleaf deciduous shrubs: temperate	x	x	x
PFT11	Broadleaf deciduous shrubs: boreal	x	x	x
PFT12	C3 plants[12]: arctic	x	x	x
PFT13	C3 plants[12]: meadow	x	x	x
PFT14	C4 plants[13]: meadow	x	x	x
PFT15	corn: dryland	x	x	x
PFT16	Corn: irrigated	x	x	x
PFT17	Wheat: dryland	x	x	x
PFT18	Wheat: irrigation	x	x	x
PFT19	Soybean: dry	x	x	x
PFT20	Soybean: irrigation	x	x	x
PFT21	cotton: dry	x	x	x
PFT22	cotton: irrigation	x	x	x
PFT23	Rice: dryland			
PFT24	rice: irrigation	x	x	x
PFT25	sugar: dry			
PFT26	sugar: irrigation			
PFT27	Other cultures: dryland	x	x	x
PFT28	Other crops: irrigation	x	x	x
PFT29	Bioenergy crops: rainfed	x	x	x
PFT30	Bioenergy crops: irrigation	x	x	x
PFT31	Urban Areas	x	x	x
PFT32	Arid	x	x	x

[12] Plants more adapted to cold and humid environments. Less efficient in carbon fixation than C4.
[13] Plants more adapted to warm, sunny environments. More efficient in carbon fixation than C3.

3. Results

3.1 Greenhouse gas projections in the different SSPs

Figure 15 illustrates the projections of greenhouse gas emissions worldwide[14] for the five SSPs without mitigation or adaptation (baseline) policies. In the same figure, the SSP1-2.6 scenario is presented, which represents a future world based on sustainable development and fulfilling the Paris agreement; the SSP2-4.5, which consists of a moderate mitigation scenario; and SSP5-8.5, which expresses a global development based on fossil fuels, with severe environmental and climatic impacts, and considered as a low probability scenario.

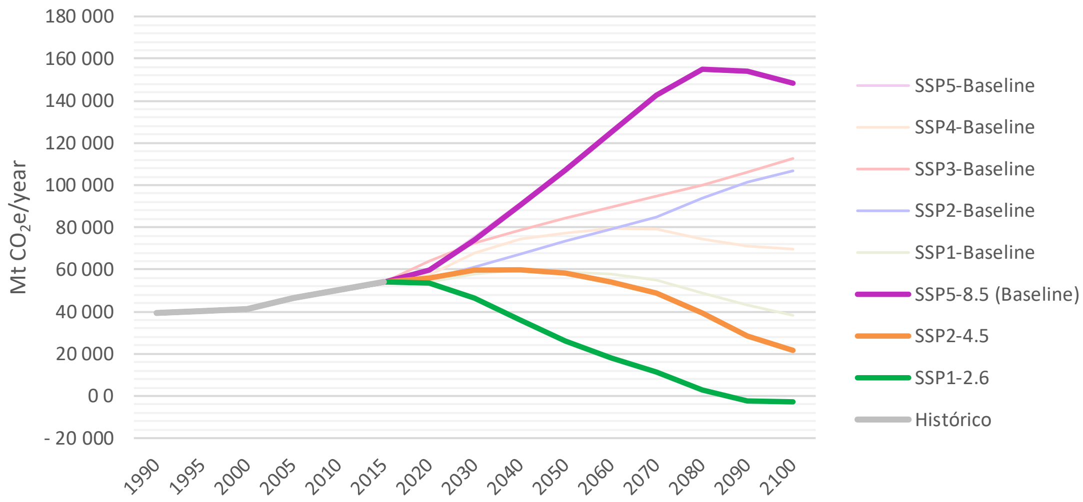


Figure 15. Projections of greenhouse gas emissions in different SSP scenarios (CO_2e). Source of emissions data: Riahi et al. (2017)

Figure 16 presents the Kyoto Protocol's greenhouse gas emissions (GHGs) disaggregated for the historical and SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios.

The SSP1-2.6 scenario is a strong mitigation scenario where CH_4 emissions are strongly reduced in all regions and energy production systems, representing an energy transition away from the burning of fossil fuels, accompanied by a decrease in cattle production. In this scenario, land use and the energy sector emissions become negative around 2030 and 2070, respectively. There is also solid international cooperation for mitigation and adaptation to climate change.

In the SSP2-4.5 scenario, mitigation is moderate, although there is a marked increase in the use of renewable energy sources. Emissions from land use become negative around 2050, and energy sector emissions after 2100. This scenario does not foresee changes to the present for emissions from the use of natural gas, agriculture, and waste. SSP5-8.5 is a scenario of no mitigation policies

[14] Expressed in CO_2e, containing the greenhouse gases defined in the Kyoto Protocol.

where development throughout the century results from fossil fuels, although emissions related to land use decrease.

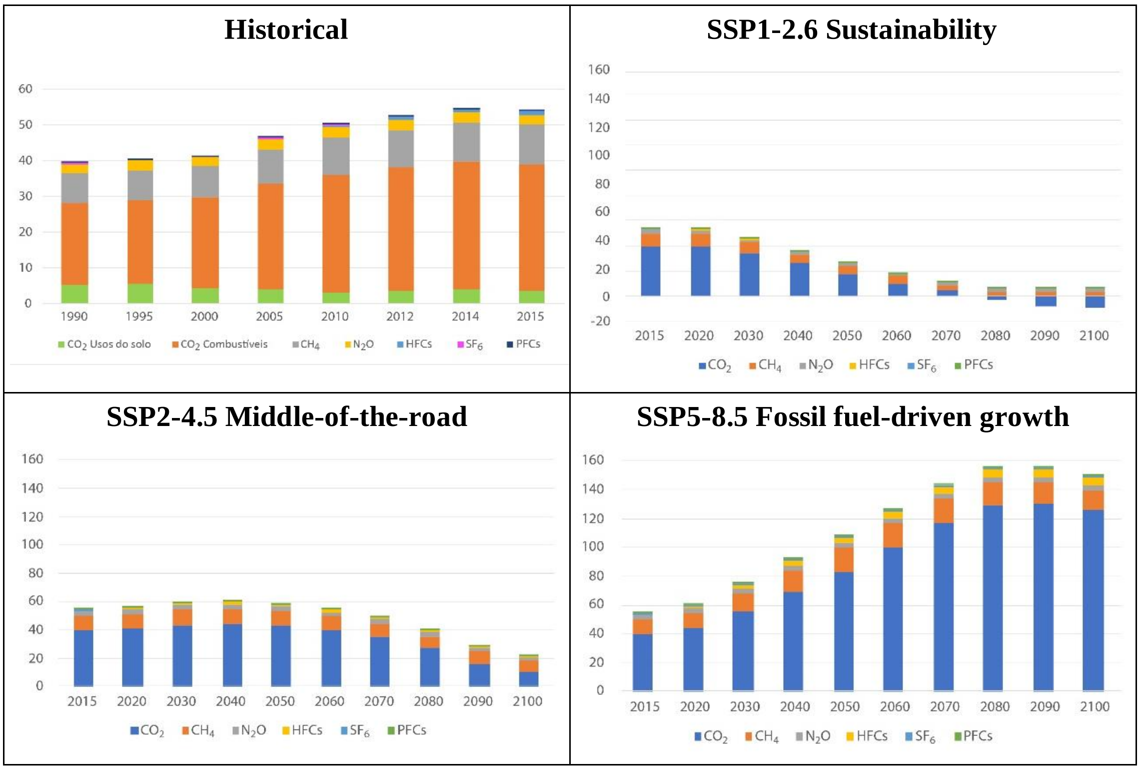


Figure 16. Observed (historical) and projected greenhouse gas emissions considering the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenario narratives

3.2 Socio-Economic Projections

This subchapter presents the main socio-economic results obtained for Portugal, resulting from the collection and processing of information from different sources of information, namely international and national.

3.2.1 Projections Based on SSP Narratives

The socio-economic results obtained for mainland Portugal in the different SSP scenarios are independent of the policy options for mitigation and adaptation, so their application is straightforward to any combination of an SSP scenario with an RCP scenario.

3.2.1.1 Population

Figure 17 explains the projection of the world population considering the narratives of each socio-economic scenario. This figure shows a considerable population increase in the SSP3 due to the lack of demographic control in developing countries. In OECD countries, including Portugal, the projection of the total population is the least favorable due to a sharp decrease in the resident population in these countries (e.g., Figure 18). The most optimistic population projections worldwide occur in SSP1 and SSP5, with an increase in population until 2050, followed by a decrease until the end of the century, where values close to the current ones are projected.

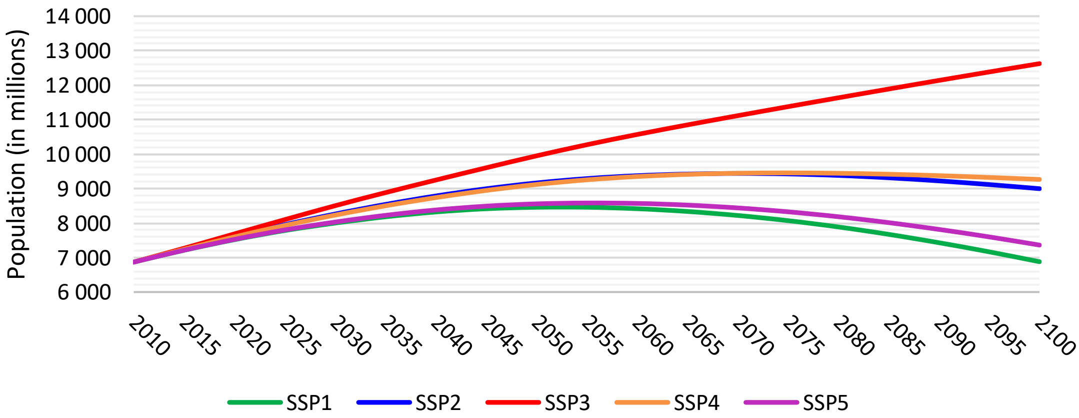


Figure 17. World population projections in the five SSPs

For mainland Portugal and since the country is part of the OECD (see scenario narratives in Table 1), the demographic projections have a very different trend in these scenarios than world trends (Figure 18 & Table 7). There is an increase in population in SSP5 (fossil fuel-based development), a relative stagnation in SSP1 (sustainability) and SSP2 (middle ground), and a decrease in population in SSP4 (inequality) and SSP3 (regional rivalry).

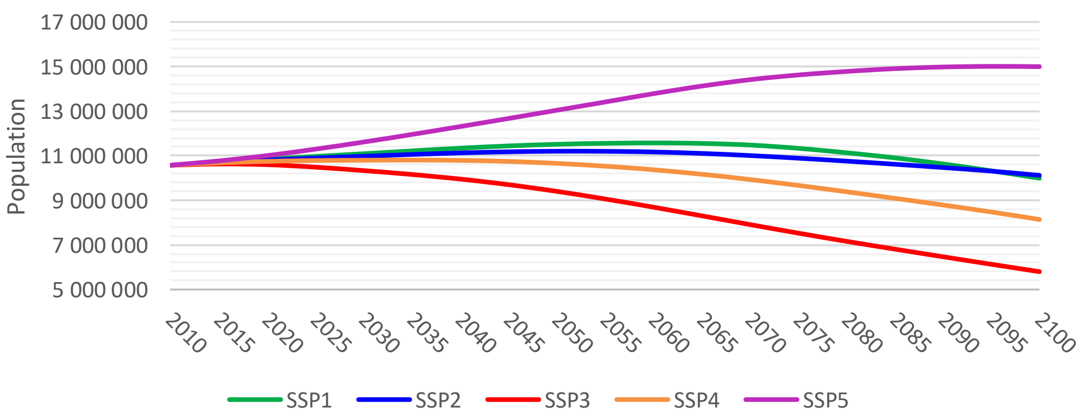


Figure 18. Projections of the population residing in mainland Portugal in the five SSPs

Table 7. Projections of the total population in the five SSPs worldwide and for mainland Portugal

Total population	2010	2025	2050	2075	2100
World (millions)					
SSP1	6,869	7,783	8,459	8,071	6,879
SSP2	6,869	7,953	9,164	9,425	8,997
SSP3	6,869	8,099	9,949	11,376	12,624
SSP4	6,869	7,932	9,119	9,455	9,265
SSP5	6,869	7,801	8,557	8,327	7,362
Portugal continental					
SSP1	10,572,721	10,967,566	11,512,340	11,332,633	9,989,358
SSP2	10,572,721	10,893,233	11,200,712	10,889,905	10,118,361
SSP3	10,572,721	10,487,416	9,403,176	7,529,918	5,800,616
SSP4	10,572,721	10,784,200	10,657,973	9,668,614	8,140,255
SSP5	10,572,721	11,292,490	13,037,369	14,620,980	14,996,050

The Aging Index expresses the relationship between the elderly population (residents aged 65 and over) and the young population (under 15 years of age).

In 2010, around 120 people aged 65 or over for every 100 residents under 15 years old in mainland Portugal. In all SSP scenarios, the relationship between young and old tends to worsen, maintaining the current criterion for calculating this indicator (Figure 19). The most favorable scenarios for this variable consist of SSP5 and SSP2, where an increase in average life expectancy is accompanied by an increase in fertility, especially in SSP5. In the case of SSP1, there is moderate fertility for mainland Portugal, combined with a considerable increase in average life expectancy, which implies the second-worst performance in this indicator. The worst-case scenario consists of SSP4, where fertility is low, combined with a moderate increase in average life expectancy (see scenario narratives in Table 1).

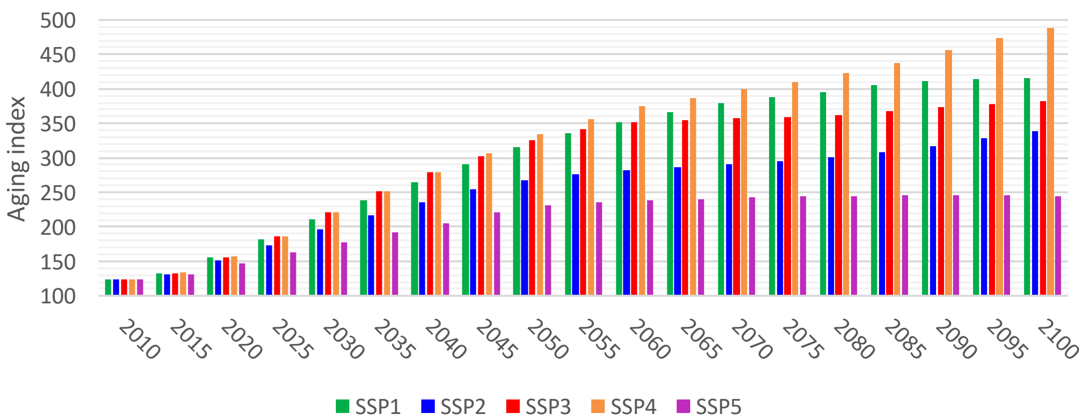


Figure 19. Aging index projections for mainland Portugal in the five SSP

The total dependency ratio seeks to answer the question of how many elderly people (people aged 65 and over) and young people (people aged less than 15 years old) exist per 100 people of working age (people between 15 and 64 years old). In 2010, there were around 50 young people and elderly people for every 100 people of working age.

In the case of the total dependency index, SSP1 presents the least favorable situation for mainland Portugal since it is a scenario with moderate fertility and a high increase in average life expectancy. The most optimistic scenario for this indicator is SSP3. However, this situation results from a higher mortality rate (see scenario narratives in Table 1).

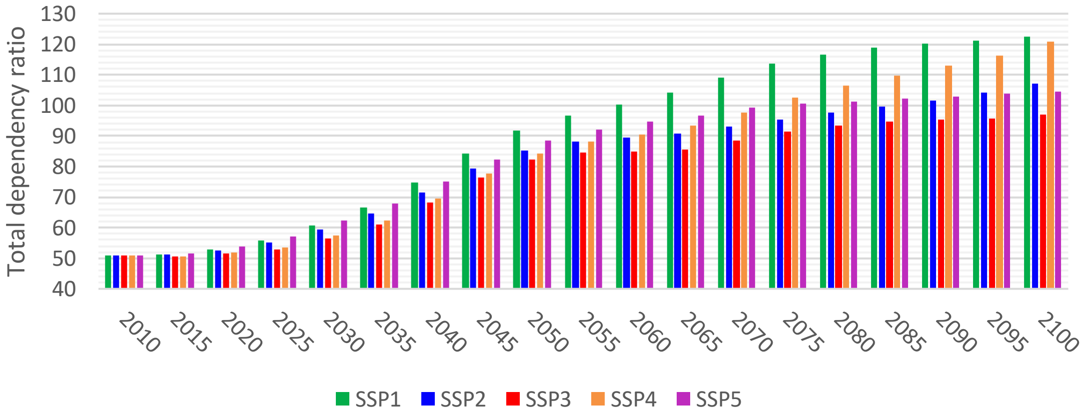


Figure 20. Projections of the total dependency ratio for mainland Portugal in the five SSP

The age pyramid for mainland Portugal in 2010 is aged, with a narrower base. Figure 21 displays the age pyramid projections for 2050 and 2100 in SSP1, SSP2, and SSP5. The most relevant trend results from the analysis of SSP5, where there is a trend of slight rejuvenation of the pyramid in the middle of the century and a situation of stationarity in 2100.

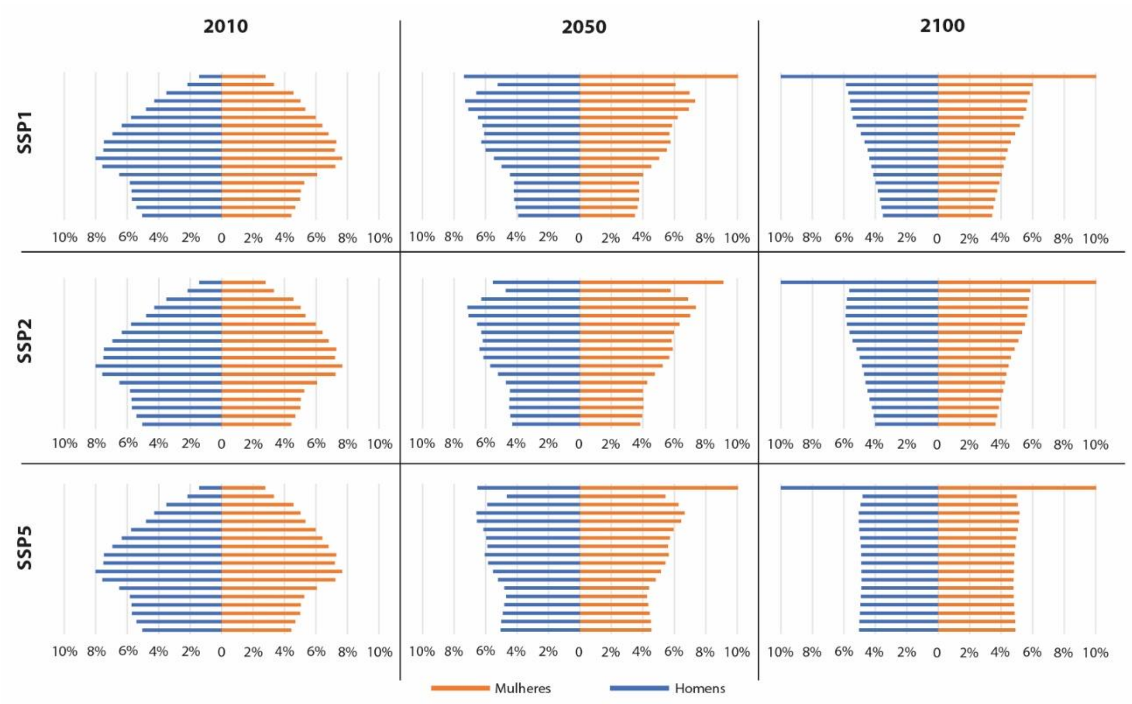


Figure 21. Age pyramids for mainland Portugal in 2010 and projections for 2050 and 2100 in the SSP1, SSP2, and SSP5 scenario

Regarding the population distribution by the NUTS II regions of mainland Portugal, and considering SSP1, SSP2 and SSP5, there is a slight increase in residents in the North and Lisbon regions until the middle of the century, followed by a decrease until 2100 in SSP1 and SSP2. In these scenarios, the remaining regions tend to decrease the total population. The SSP5 scenario projects an increase in the total population in all regions, being more pronounced in the North Region and Lisbon. This trend tends towards stationarity at the end of the century (Figure 22).

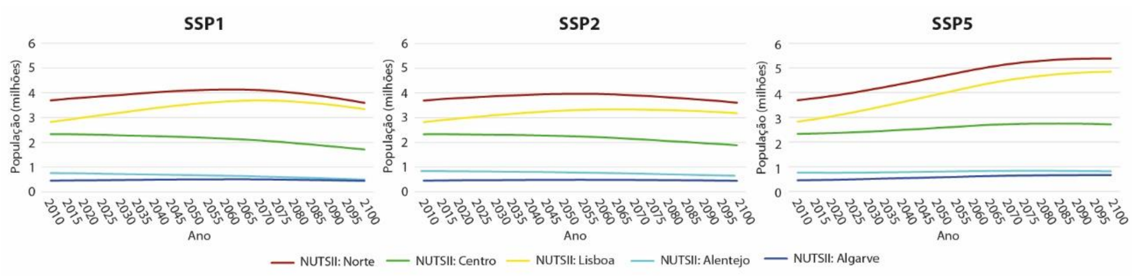


Figure 22. Population projection for the NUTS II regions of mainland Portugal until 2100 and in the SSP1, SSP2, and SSP5 scenario

Concerning the projections for the population residing in urban areas, there is, for Portugal, a high increase in concentration in SSP1 and 5, a moderate increase in SSP2 and SSP4, and a low increase in SSP3, following the narratives of each scenario (see Table 1).

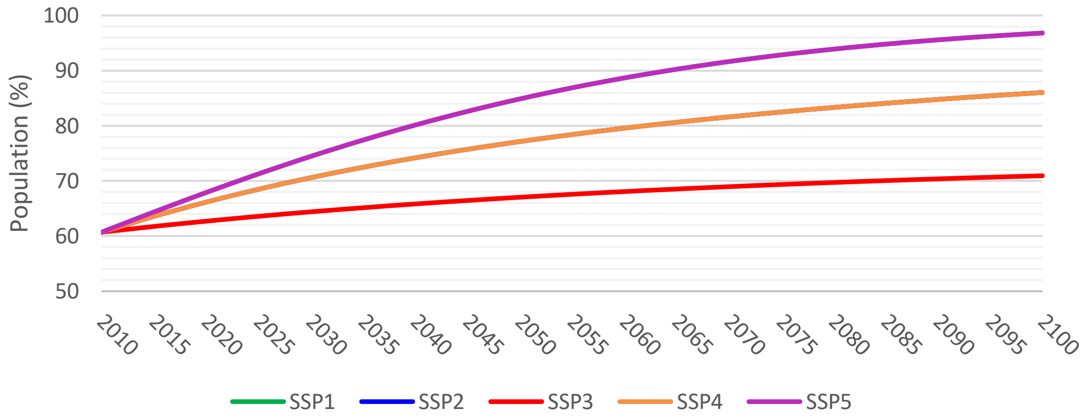


Figure 23. Projection of the percentage of population residing in urban areas for Portugal in the five SSP. SSP1 and SSP5 have the same trends under the narratives of these scenarios, as well as SSP2 and SSP4

3.2.1.2 GDP

The projections of the Gross Domestic Product, carried out by the OECD within the scope of the SSP, indicate the highest growth of the world economy associated with the SSP5. In the opposite direction are the SSP3 projections, and with moderate growth are the remaining scenarios (Figure 24).

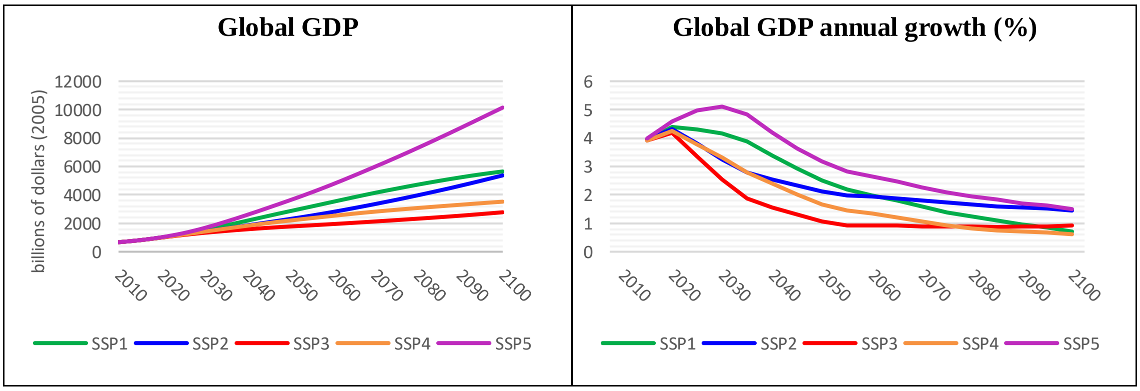


Figure 24. Global GDP (billions of dollars - 2005) and average annual GDP growth rate in the five SSP, relative to 5-year periods. Source: Dellink et al. (2017b)

The Portuguese tendencies in each SSP are aligned with the global projection trends for the respective scenario (Figure 25). Once again, these tendencies are consistent with the narratives of each scenario (see Table 1).

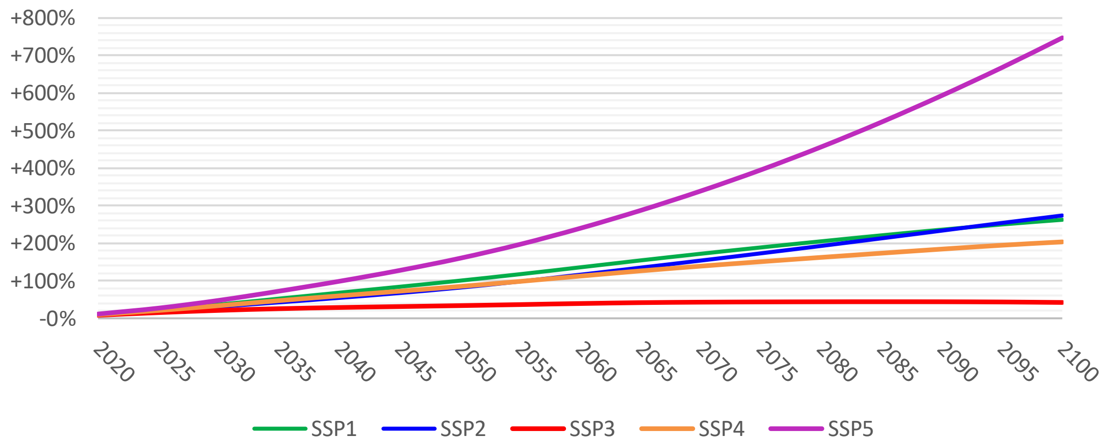


Figure 25. Percentage of Change in GDP for the year 2015 for Portugal in the five SSP

Regarding the annual GDP growth rate (%) for Portugal, the SSP5 scenario presents a higher rate. At the same time, the SSP3 implies a worse performance of the economy, reaching negative growth values by the end of the century. The remaining three scenarios present an intermediate projection of the annual rate of GDP.

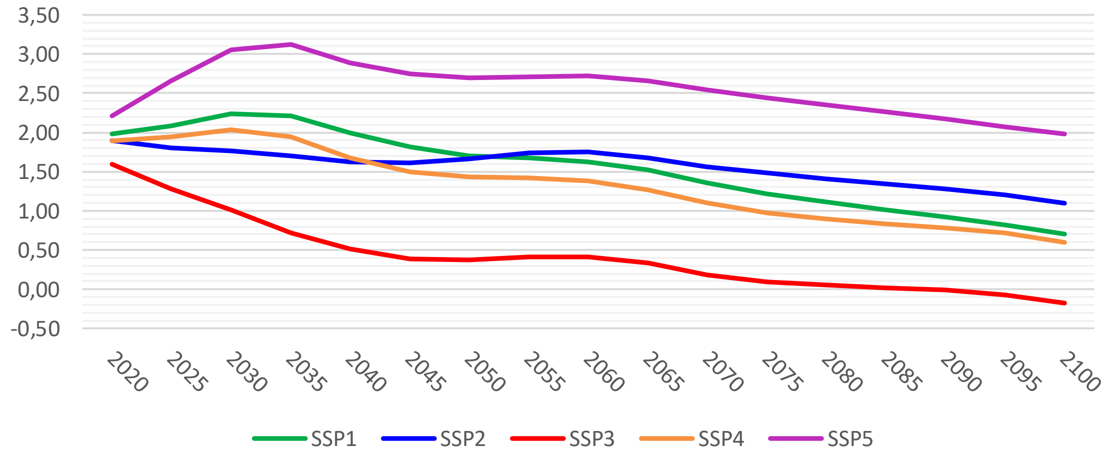


Figure 26. Average annual GDP growth rate (% per year) for Portugal in the five SSP, relative to 5-year periods

3.2.2 Socio-Economic Projections Based on Other International Sources

Demographic projections collected from other international information sources are shown in Figure 27.

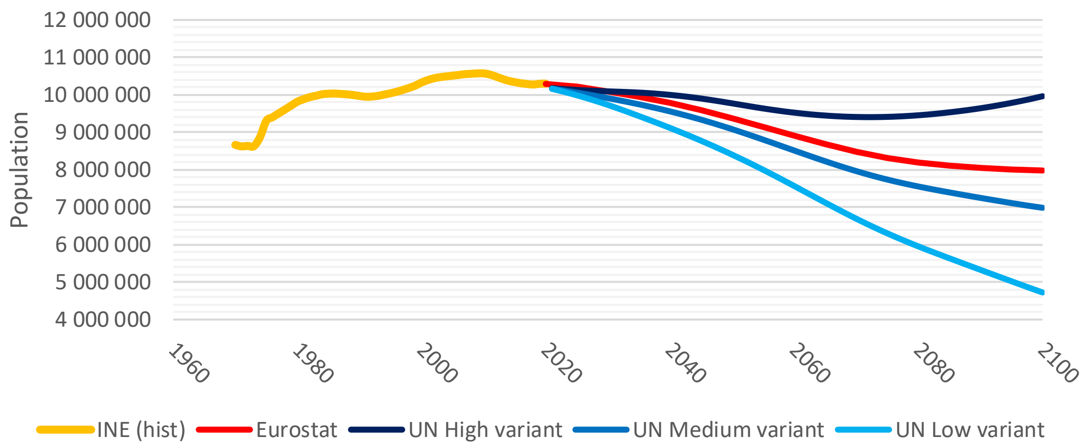


Figure 27. Demographic projections for Portugal until 2100, according to Eurostat and the United Nations.

When comparing the projection made by Eurostat and the average variant of the United Nations, there is a relatively similar trend in the trajectory of the projection, although the total population values for Portugal decrease more sharply in this United Nations projection.

The identified differences result from methodological differences between the two approaches and/or from the assumptions adopted in defining the baseline scenario, as described in the methodology chapter.

Eurostat's projected population decrease reaches a reduction of 2.3 million inhabitants in 2100 compared to the reference situation. However, this decrease is not the same in all NUTS III regions, with two regions where an increase in the resident population is projected (Table 8).

Table 8. Projected total population for Portugal's NUTS III by Eurostat. The color scale varies between shades of green and red. The values in green are related to the periods where the largest number of populations is found in the region, and the values in red are those with the lowest number.

NUTS III	2020	2030	2040	2050	2060	2070	2080	2090	2100
Alto Minho	230,742	219,045	207,018	193,268	179,318	167,171	157,805	151,460	147,263
Cávado	404,741	399,578	387,335	364,694	337,098	310,222	289,032	274,124	263,837
Ave	412,327	397,450	376,263	345,297	311,024	280,247	256,630	239,311	226,706
AM do Porto	1,723,588	1,681,021	1,607,942	1,504,998	1,389,834	1,283,069	1,202,219	1,146,325	1,103,722
Alto Tâmega	86,171	79,433	72,924	66,415	60,841	56,641	53,246	50,309	48,153
Tâmega e Sousa	416,465	400,184	379,469	348,949	314,197	283,238	258,502	238,499	222,973
Douro	190,496	178,678	166,842	152,935	138,734	126,547	116,388	107,899	101,313
Terras de Trás-os-Montes	107,549	99,913	92,415	84,900	78,175	72,794	68,762	65,870	64,035
Algarve	441,061	443,024	442,867	440,108	435,577	431,943	434,680	444,975	458,163
Oeste	357,496	353,255	346,095	333,788	317,700	301,302	287,902	277,445	268,476
Região de Aveiro	362,884	357,987	347,182	329,844	309,557	290,477	276,037	265,860	258,439
Região de Coimbra	432,805	407,956	381,753	353,105	323,616	297,232	278,180	266,259	257,447
Região de Leiria	284,304	273,683	261,274	245,566	228,322	212,547	200,578	192,309	186,280
Viseu Dão Lafões	251,498	236,956	222,525	206,400	189,989	175,538	163,903	155,135	148,437
Beira Baixa	80,075	72,331	66,356	60,649	55,245	50,536	46,888	44,447	42,647

NUTS III	2020	2030	2040	2050	2060	2070	2080	2090	2100
Médio Tejo	231,944	218,725	206,820	192,824	177,562	164,124	153,456	144,826	137,950
Beiras e Serra da Estrela	211,663	190,861	172,484	154,227	137,695	124,555	114,858	107,896	102,831
AM de Lisboa	2,868,520	2,956,064	2,995,713	3,020,855	3,029,203	3,026,977	3,062,494	3,142,647	3,232,623
Alentejo Litoral	93,181	88,367	83,546	78,606	73,919	70,166	67,681	66,939	67,124
Baixo Alentejo	115,559	105,170	97,048	89,470	82,489	76,792	73,065	71,115	70,201
Lezíria do Tejo	236,451	221,828	208,234	194,010	179,296	166,178	156,460	150,481	145,923
Alto Alentejo	104,106	91,222	81,667	72,579	64,301	57,509	52,876	50,229	48,587
Alentejo Central	151,385	135,636	122,280	109,647	97,735	87,571	80,434	76,366	73,714
RA dos Açores	242,704	236,522	227,414	214,674	199,985	185,161	171,482	160,676	152,550
RA da Madeira	253,742	244,249	233,166	217,539	199,431	182,949	169,703	159,329	151,245
Portugal	10,291,457	10,089,138	9,786,632	9,375,347	8,910,843	8,481,486	8,193,261	8,050,731	7,980,639

The NUTS III regions where population dynamics will tend to improve, in terms of the total population, consist of the Lisbon Metropolitan Area (AML) and the Algarve region, although with different behaviors. In the AML, Eurostat projects an increase in the total population decade after decade. In contrast, in the Algarve region, the total population will decrease until 2080, followed by an increase until the end of the century, which may exceed the total values for 2020. In this context, It should also be noted that the population growth projected for the AML could reach values around an increase of 400 thousand inhabitants in 2100, while in the Algarve, the variation is around less than 10 thousand inhabitants in 2080 and a further 10 thousand inhabitants in 2100, compared to the year 2020.

Around the middle of the century the age population structure is projected to change: the working-age population will decrease while the elderly population increases. This structure tends to become more balanced towards the end of the century (Figure 28).

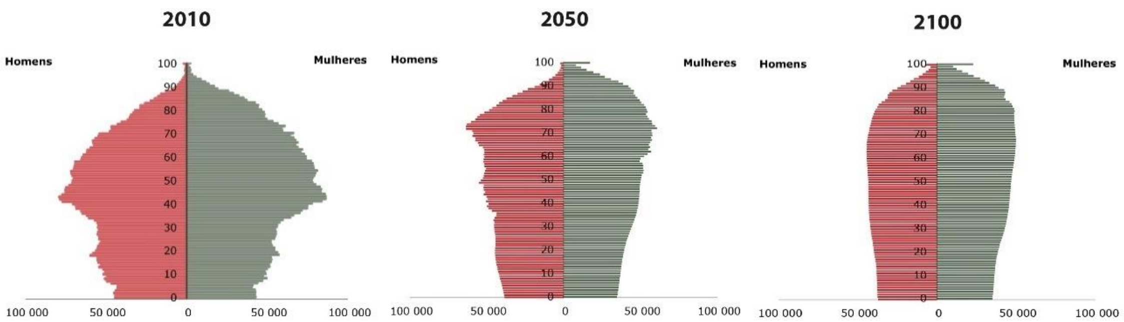


Figure 28. Age pyramids for Portugal in 2010 and projections for 2050 and 2100, based on Eurostat data. Source: adapted from Nunes 2020

The Department of Economic and Social Affairs of the European Union projected some macroeconomic variables that integrate Eurostat's demographic projections, such as the GDP growth rate for Portugal until 2070. A summary of these projections is presented in Table 9.

Table 9. Macroeconomic assumptions prepared by the Department of Economic and Social Affairs of the European Union and published within the scope of the 2021 Aging Report. The values presented are rounded to the first decimal place. Source: EC (2021)

Average Macroeconomic Assumptions (Growth rate (%))	Average (2019-2070)	2019	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
Potential GDP	1.2	1.8	0.9	0.7	1.0	1.2	1.2	1.3	1.4	1.4	1.3	1.2
Job	-0.5	1.4	-0.4	-0.7	-0.9	-0.9	-0.9	-0.6	-0.4	-0.4	-0.4	-0.4
Worked hours	-0.5	1.3	-0.4	-0.7	-0.9	-0.9	-0.9	-0.6	-0.4	-0.4	-0.4	-0.3
productivity per hour	2.3	3.2	3.3	3.2	2.6	2.2	2.2	2.1	1.9	1.8	1.7	1.5
GDP per potential capita	1.6	1.8	1.1	1.0	1.3	1.5	1.7	1.8	2.0	1.9	1.8	1.6
GDP per potential worker	1.7	0.4	1.3	1.4	1.9	2.1	2.1	2.0	1.9	1.8	1.7	1.6

These projections indicate a GDP growth rate of less than 1% for Portugal until 2035. From that period onwards, the growth rates increase slightly but never exceed the 2019-value (Figure 29).

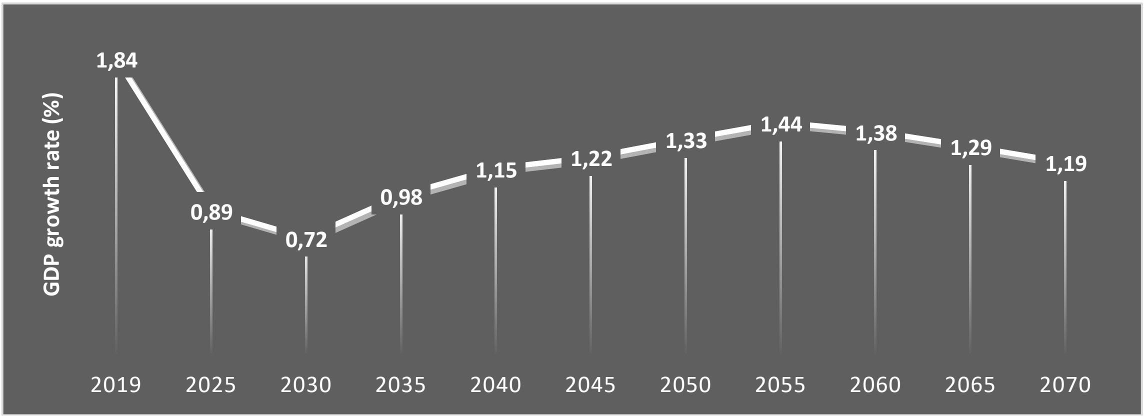


Figure 29. Projected GDP growth rate for Portugal according to the Aging Report. Source: EC (2021)

3.2.3 Socio-Economic Projections Based on National Data

INE defines three primary projections of the resident population until 2080. The central projection has the most excellent consistency, considering the trends observed for the different demographic variables (INE, 2017b). In this scenario, there is a tendency for the total population to decrease until 2080, with reduced values of around two million inhabitants (Table 10). This value is close to that projected by Eurostat for the same year, although the evolution between 2020 and 2080 is relatively different between both projections (see Table 8).

Table 10. Projections of the resident population for Portugal until 2080. Source INE (2020b)

Portugal	2020	2030	2040	2050	2060	2070	2080
High	10,350,415	10,602,928	10,715,723	10,701,920	10,614,968	10,535,644	10,555,447
Central	10,330,240	10,295,824	10,046,681	9,647,698	9,157,001	8,647,928	8,216,015
Low	10,302,981	9,971,365	9,360,824	8,585,634	7,718,741	6,839,478	6,057,479

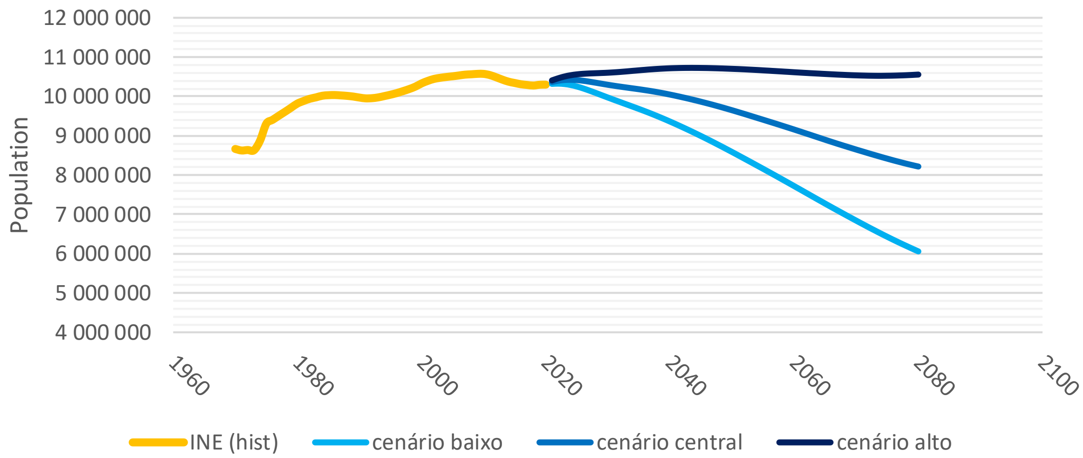


Figure 30. Resident population projections for Portugal until 2080. Source INE (2020b)

The optimistic projection, called the high scenario, projects a stabilization of the resident population by 2080, while the low scenario indicates a much more accentuated loss of total population than the central scenario, reaching values of around four million fewer inhabitants in Portugal. in the year 2080 (Figure 30).

Regarding the distribution of the resident population by NUTS II, INE projections indicate a progressive decrease in the population for the North, Center, and Alentejo in all projections. For the Algarve and Lisbon Metropolitan Area regions, the resident population tends to increase throughout the century, both in the central and high scenarios, decreasing the total population in the low scenario (Figure 31).

In this context, it should be noted that both the INE and Eurostat population projections for the regions of the Algarve and the Lisbon Metropolitan Area indicate an increase in the resident population when comparing the central scenario with the Eurostat projection. However, the trends and the total values are different. For example, Eurostat's projection indicates a decrease in population in the Algarve region until 2080, while INE projects an increase until that period. Recall that Eurostat's projected rise in population in the Algarve region takes place after 2080 when comparing the total population values with the year 2020 (see Table 8).

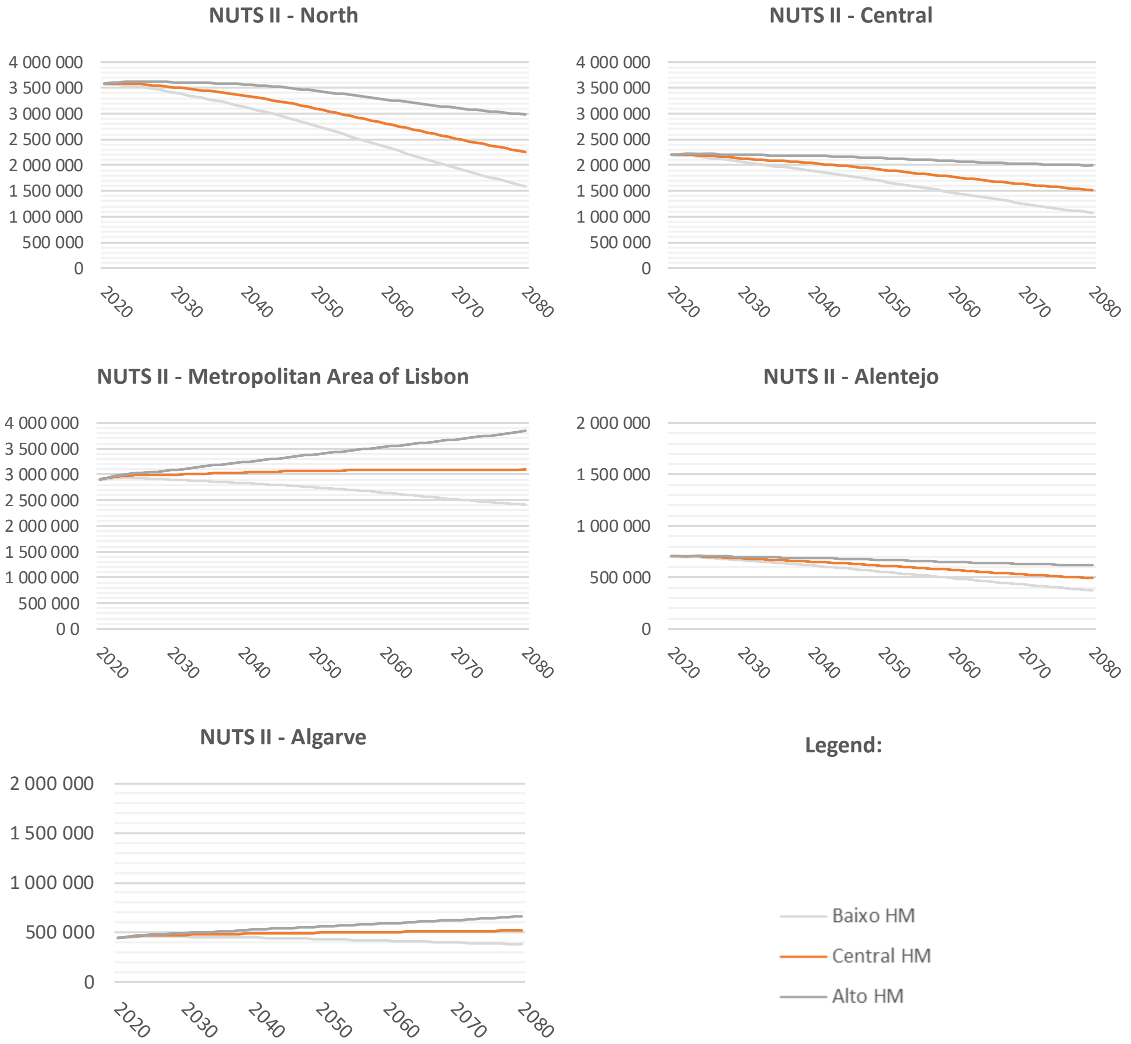


Figure 31. Projection of the resident population in the NUTS II regions of mainland Portugal. Source: INE (2020b)

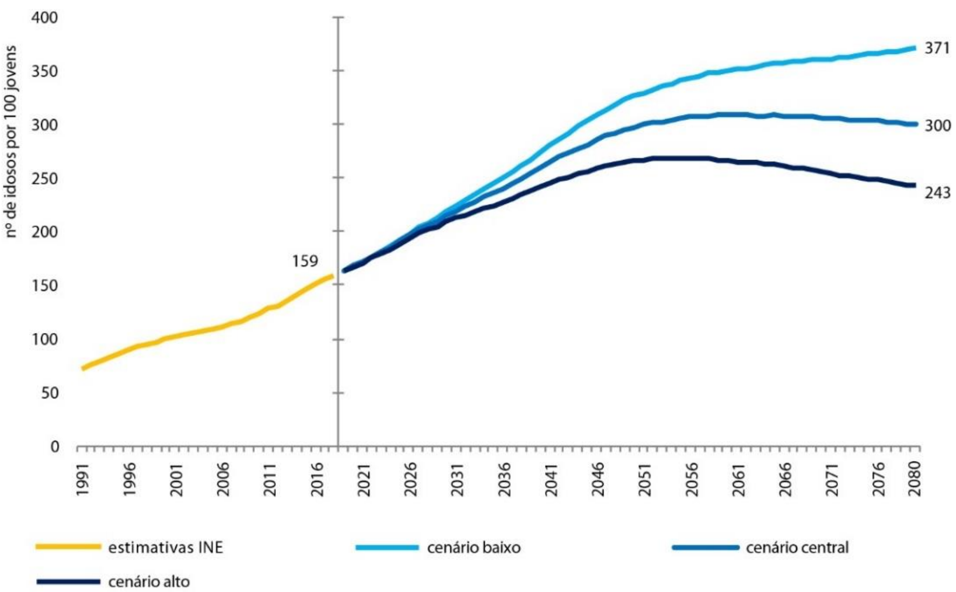


Figure 32. Projected aging index for Portugal until 2080. Source: adopted from INE (2020b)

Regarding the aging index, in 2018, INE's estimate shows about 159 people aged 65 or older per 100 residents under 15 years old in Portugal. The projected ratio between the elderly and young population tends to worsen (increase) in all scenarios undertaken. In the central scenario, the value projected for 2080 is 300.3 elderly per 100 young people. However, the highest value is projected for 2060, when the index value reaches 308. This change may indicate a progressive improvement in this index in subsequent years, i.e., the aging index will only tend to stabilize in the vicinity of 2050 when the generations born in a context of fertility levels below the threshold of generational replacement are already in the age group 65 and older (Figure 32).

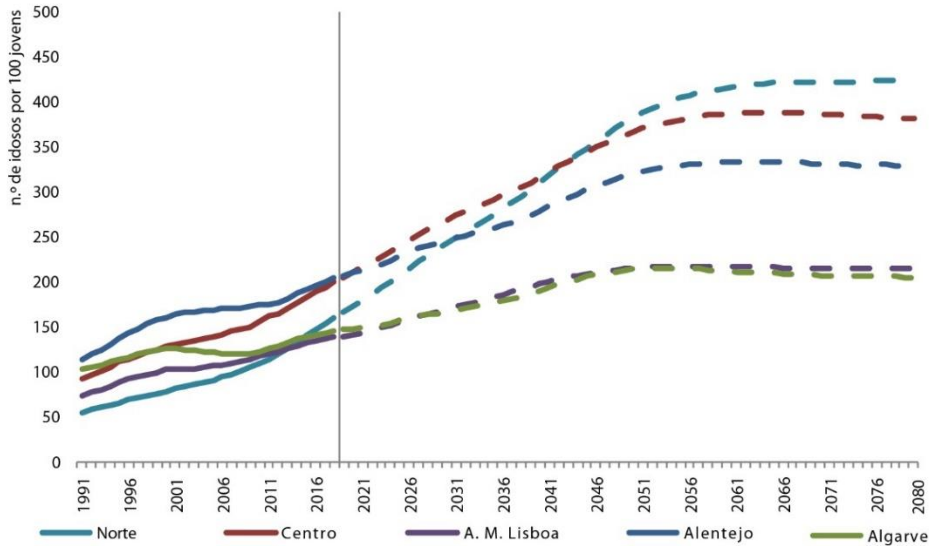


Figure 33. Projected aging index for the NUTS II of mainland Portugal until 2080, considering the central scenario. Source: adopted from INE (2020b)

The projected changes in the aging index by the NUTS II region of mainland Portugal and for the central scenario foresee significant changes in the population structure compared to the current situation. In this context, the regions with an index above the national average for 2080 consist of the Northern (424), Centro (380.7), and Alentejo (329.0) regions, while the AML (213.9) and Algarve (204.4) regions show a value below the national average for that year, the latter being the least aged in the country.

The trend in the Northern Region deserves special mention since this region was the youngest in 1991 among the regions of continental Portugal (Figure 33).

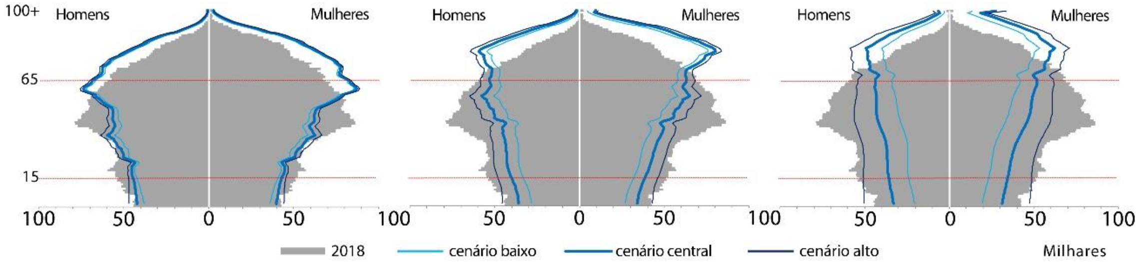


Figure 34. Age pyramids for Portugal in the low, central, and high scenarios for 2035 (left), 2055 (center), and 2100 (right), compared to 2018 values. Source: adopted from INE (2020).

Regarding the population structure and, in general, the different projections indicate a progressive increase in the elderly population and a narrowing of the age pyramids at the base, which reflects a decrease in the birth rate. Among the scenarios made available by INE, the high scenario is the only one that projects birth rates higher than the current ones for the end of the period of analysis, which may translate into a reversal of trends and may lead to a rejuvenation of the age pyramid at the base at the end of the 21st century, albeit in a minimal way (Figure 34).

Finally, and concerning socio-economic data, it should be noted that no medium or long-term economic projections by national institutions were found. However, INE compiles this information over the years, and a summary is presented in Table 11.

Table 11. Real GDP growth rate. Data Sources: INE - Annual National Accounts (Base 2016)

1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
3.91	3.82	1.94	0.77	-0.9	1.79	0.78	1.63	2.51	0.32	-3.1	1.74	-1.7	-4.1	-0.9	0.79	1.79	2.02	3.51	2.85	2.68

3.3 Land use projections in the SSP

The land use projections for Iberia presented in Figure 35 reflect the overview of the land use narratives for SSP1, SSP2, and SSP5 (see Table 3), although these projections are appropriately adjusted to RCP2.6, RCP4.5, and RCP8.5, respectively.

In SSP1-2.6, forest areas are projected to increase in the Iberian Peninsula, resulting in a considerable increase in sinks. Also, the crops related to bioenergy tend to increase, occupying approximately 10% of the territory in 2100. These modifications imply decreasing shrublands and pastures and a slight decrease in rainfed and irrigated crops.

In the SSP2-4.5 scenario, the forest cover is maintained. In this scenario, it is projected that the territory occupied with bioenergy crops will reach values close to 15% in 2100. The land uses with a tendency to decrease consists of grasslands and shrublands.

Regarding the SSP5-8.5 scenario, there is a decrease in rainfed and irrigated crops, except for crops associated with bioenergy (occupied territory will reach 3%). Some forest species may slightly increase their occupied area in the Iberian Peninsula.

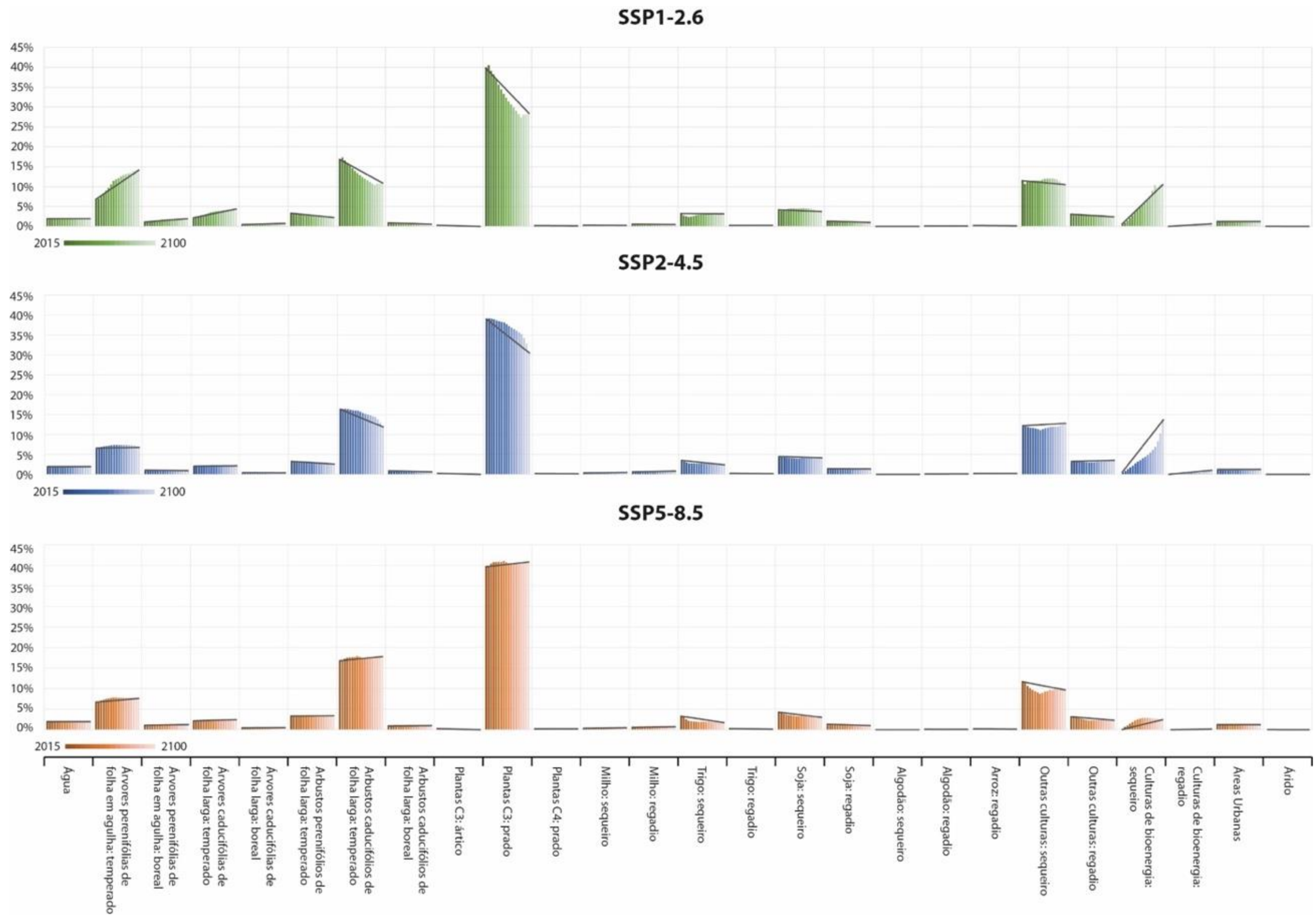


Figure 35. Land use projections for Iberia in scenarios SSP1-2.6, SSP2-4.5 and SSP5-8.5

3.4 Comparison with the roadmap to carbon neutrality 2050 (RNC2050)

3.4.1 RNC2050 and SSPS

Comparing the projections of the SSP scenarios with the scenarios of the Roadmap for Carbon Neutrality allows us to verify that the three trajectories of the RNC2050 have socio-economic indicators broadly aligned with those of the less optimistic SSP for a given variable. For example, Figure 36 presents the population projection for Portugal, and two of the three RNC2050 scenarios are below SSP3. Only the "Camisola Amarela" scenario shows a more favorable trend and can be compared with SSP4.

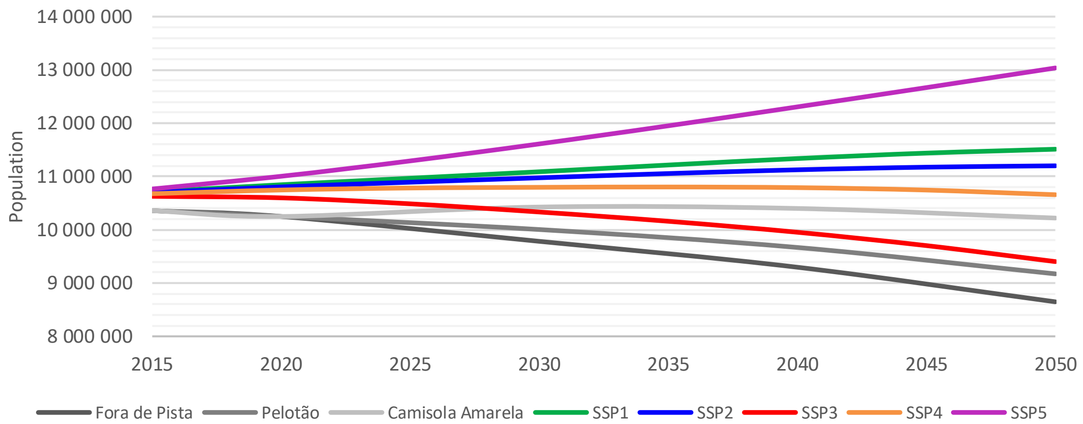


Figure 36. Comparison between the SSP and the Roadmap 2050 scenarios projections for total national population

When the comparison is made for the aging index, the projections of the "Fora da pista" scenarios are aligned with SSP3 and/or SSP4, and the "Peletão" scenario can be compared with SSP1 and the "Camisola Amarela" with SSP2 (Figure 37). In this comparison, it should be kept in mind that the start of the demographic scenarios is different, i.e., the RNC2050 has 2015 as its starting point, while the SSP scenarios had their start in 2010. However, the comparison coincides with the beginning of the series in 2015, although this overlap is not part of the figures presented.

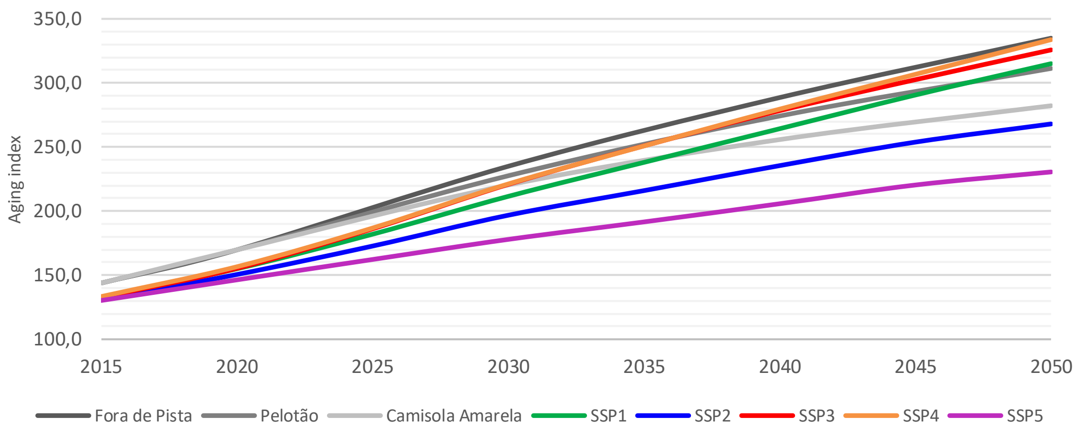


Figure 37. Comparison between the projections of the SSP scenarios and the Roadmap for Carbon Neutrality 2050 regarding the aging index

Regarding the total dependency index, the "Fora da pista" and "Peletão" scenarios can be compared to SSP5, and the "Camisola Amarela" is close to SSP2 (Figure 38). Again, it is essential to keep in mind that this analysis results from matching the values in 2015, as noted above.

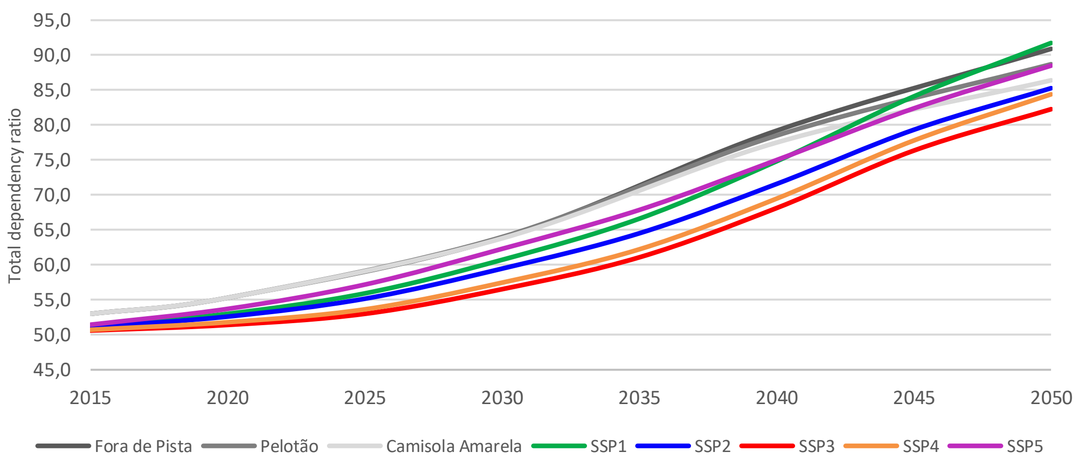


Figure 38. Comparison of the SSP and Roadmap 2050 scenarios projections for total dependency ratio

Comparing the projected evolution of GDP for the two sets of scenarios under analysis has 2020 as the starting year of the series. In this case, the less optimistic projection of the RNC2050 is coincident with the less favorable of the SSP set (SSP3). The remaining projections of RNC2050 are between this scenario (SSP3) and SSP2.

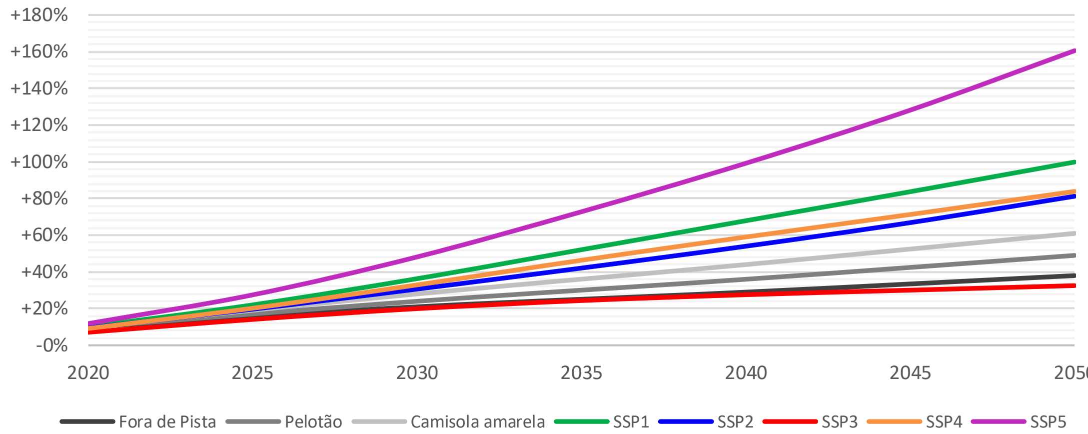


Figure 39. Comparison between the SSP scenarios and the 2050 Carbon Neutrality Roadmap projections, relative to the percentage change in GDP

Figure 40 and Figure 41 present the projections of land use changes made under the RNA 2050 for the "Camisola Amarela" and "Peletão" scenarios, respectively.

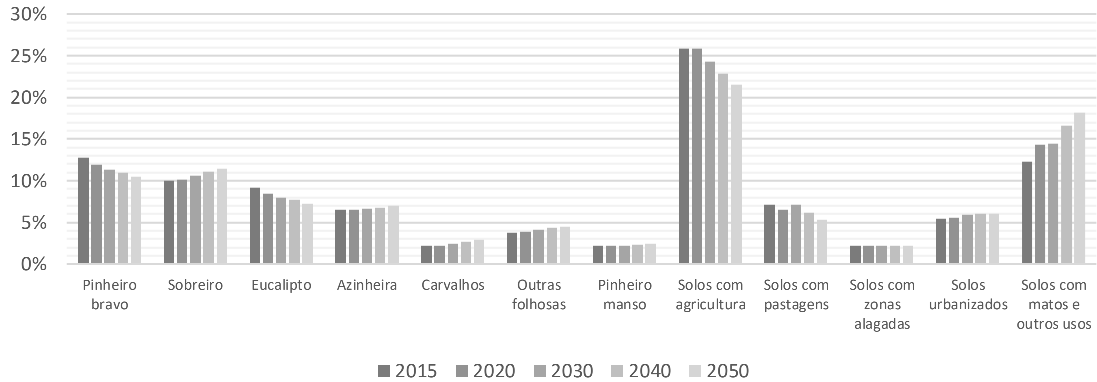


Figure 40. Projections of land use in the "Camisola Amarela" scenario developed under the RNC2050. Source APA (2012)

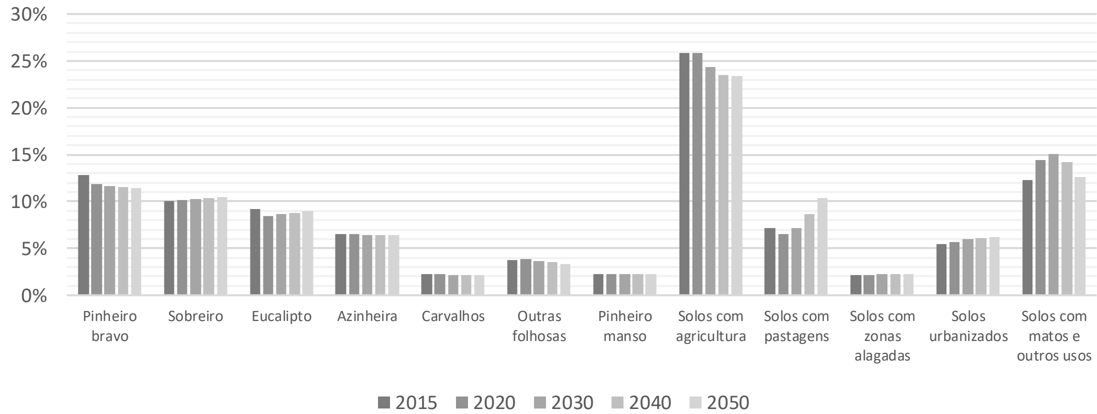


Figure 41. Land use projections in the "Peletão" scenario, developed under the RNC2050. Source: APA (2012)

To compare the SSP-RCP and RNC2050 land use classes, a commonality was made based on three generic classes, as Chen et al. (2020) suggested: forest, non-forest, and agriculture. Table 12 presents the three generic classes and their correspondences concerning the classes referred to in the database used to characterize the SSP-RCP and the RNC2050.

Table 12. Presentation of the generic land use classes as suggested in Chen et al. (2020) and their correspondence with the land use classes available in the SSP-RCP and RNC2050 scenarios

Generic Classes	SSP-RCP Classes	RNC2050 Classes
Forest	i) Evergreen needle-leaf trees: temperate, ii) Evergreen needle-leaf trees: boreal, iii) Deciduous broadleaf trees: temperate, iv) Deciduous broadleaf trees: boreal	i) Maritime pine, ii) Cork oak, iii) Eucalyptus, iv) Holm oak, v) Oak, vi) Other broadleaf, vii) Umbrella pine, viii) Other coniferous
Non-forest	i) Water, ii) Evergreen broadleaf shrubs: temperate, iii) Deciduous broadleaf shrubs: temperate, iv) Deciduous broadleaf shrubs: boreal, v) C3 plants: arctic, vi) C3 plants: grassland, vii) C4 plants: grassland, viii) Areas, ix) Urban, x) Arid	i) Soils with grasslands, ii) Soils with wetlands, iii) Urbanized soils, iv) Soils with bushes and other uses
Agriculture	i) Maize: non-irrigated, ii) Maize: irrigated, iii) Wheat: non-irrigated, iv) Wheat: irrigated, v) Soybean: non-irrigated, vi) Soybean: irrigated, vii) Cotton: non-irrigated, viii) Cotton: irrigated, ix) Rice: irrigated, x) Other crops: non-irrigated, xi) Other crops: irrigated, xii) Bioenergy crops: non-irrigated, xiii) Bioenergy crops: irrigated, i)	i) Soils with agriculture

Figure 42 and Figure 43 graphically present the aggregation of land use classes for the SSP-RCP scenarios and RNC2050 scenarios, respectively.

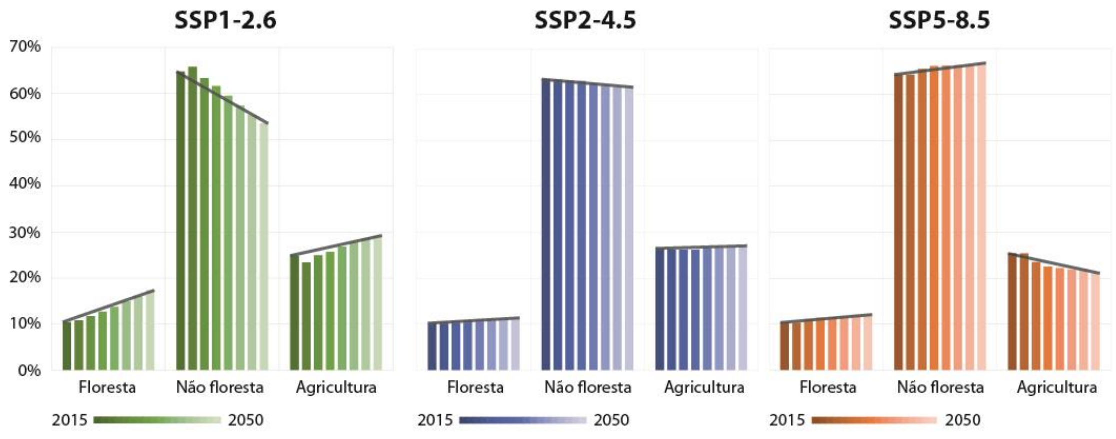


Figure 42. Land use projections for the Iberian Peninsula in the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios grouped into three overarching classes referred to in Chen et al. (2020)

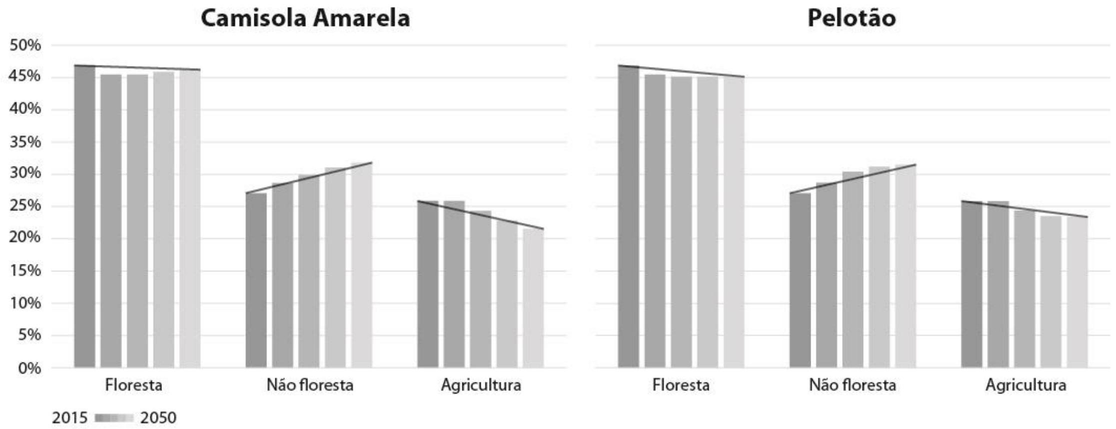


Figure 43. Land use projections under the "Camisola Amarela" and "Peletão" scenarios developed under RNC2050 and grouped into three overarching classes referred to in Chen et al. (2020). Source: APA (2012)

Comparing the projections presented in RNC2050, we see that "Camisola Amarela" and "Peletão" scenarios project very slight decreases followed by maintenance of forest area, a slight increase in non-forest area, and a slight decrease in the agricultural area. These trends show more similarities with SSP5-8.5 than with the other SSP-RCP scenarios.

This comparison is nevertheless substantially dubious for two reasons:

- The coverage area is distinct, being the Iberian Peninsula in the case of the SSP-RCP scenarios and Portugal in the case of the RNC2050; thus, it is only possible to analyze general trends and not absolute values;
- The definition of each land use class presented in the RNC2050 is not clarified (lack of metadata), so it is not certain that the classes have been correctly grouped.

3.4.2 RNC2050 and other Sources of information

The comparison of the projections prepared by the United Nations and Eurostat with the Carbon Neutral Roadmap allows us to verify that the three trajectories of the NREN2050 have demographic indicators broadly aligned. In detail, the RNC2050 scenarios are slightly more optimistic in relation to the total population projected for Portugal than those of the United Nations. This comparison results from the expectation that the "Fora da pista" scenario is comparable to the high UN projection, the "Peletão" scenario comparable to the medium scenario, and the "Fora da pista" scenario to the low scenario (Figure 44).

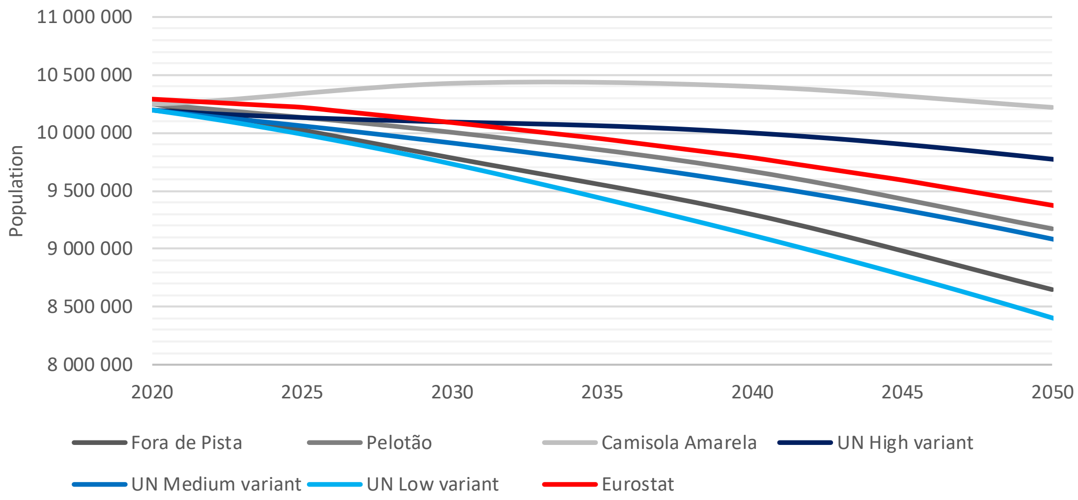


Figure 44. Comparison between projections from international sources (Eurostat and United Nations) and the Roadmap for Carbon Neutrality 2050 concerning the total population of Portugal

When comparing the Eurostat projection with the central RNC2050 projection ("Peletão"), a concordance in trends is observed: the total population loss for Portugal is slightly less pronounced in the Eurostat projection.

Figure 45 illustrates the comparison between the RNC2050 projections and INE's most recent population projections. Since the RNC2050 used data from INE that referred to a previous version of population projections for Portugal, it is expected that there is a high level of comparability between the different scenarios since the methodology adopted did not change significantly between exercises.

The RNC2050 adopted the INE projections published in 2017 (INE, 2017c), with the Off-Plan Scenario considering "the scenario without migrations from INE (with the fertility and mortality evolution of the central scenario, minus the impact of migration flows). As for the "Peletão" Scenario, the projections followed INE's central scenario. For the "Camisola Amarela" Scenario, the projections respected INE's central scenario for 2020 and INE's high scenario between 2021-2050" (Barata et al., 2018).

In this context, the most remarkable modifications introduced by the RNC2050 scenarios to the INE scenarios consist of the "Fora da pista" scenario. This projection shows a tremendous disagreement with the new INE scenarios compared to the low scenario. The remaining two scenarios ("Peletão" vs. central and "Camisola Amarela" vs. high scenarios) show identical trends. However, the new INE projections show higher absolute values of the total population for Portugal (Figure 45).

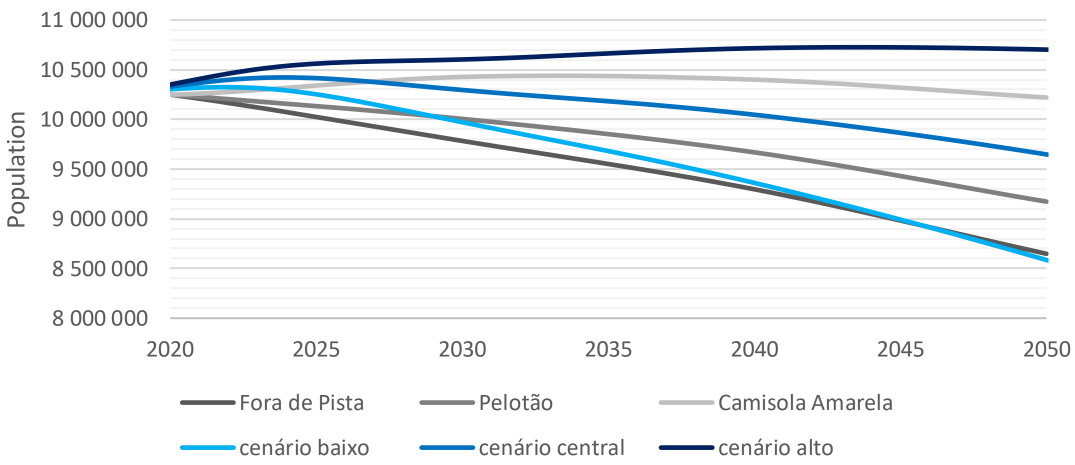


Figure 45. Comparison between the projections made by INE and the Roadmap for Carbon Neutrality 2050 concerning the total population of Portugal

We see a slight time lag in the aging index worsening between the new INE projections and the RNC2050 projections, although the trends are the same (Figure 46).

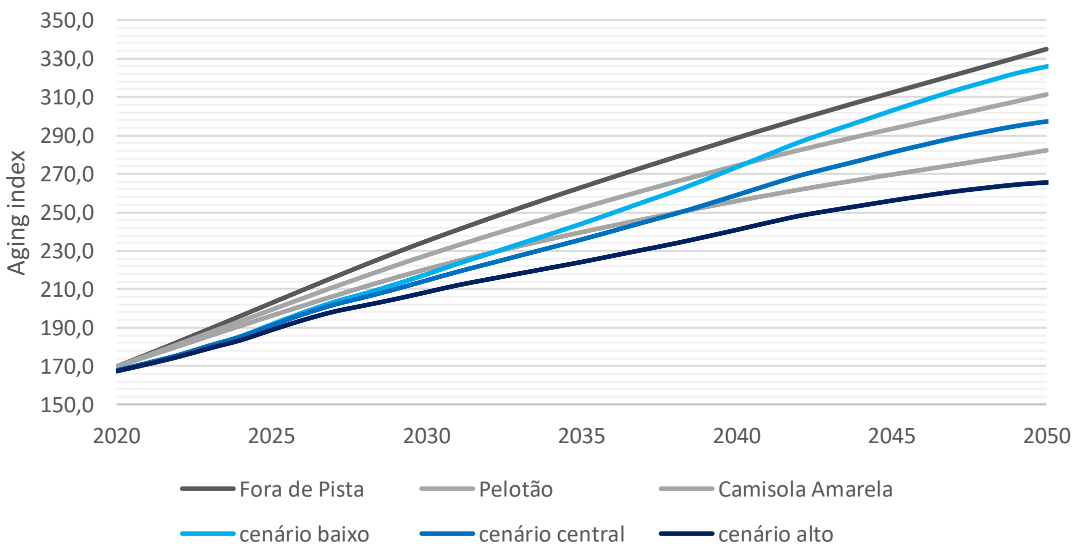


Figure 46. Comparison between the projections made by INE and the Roadmap for Carbon Neutrality 2050 concerning the aging index for Portugal

4. Discussion and conclusions

As shown, there is a great diversity of sources of information related to **demographic projections** and applicability to the Portuguese context. SSP/SPA scenarios are wealthy, containing development assumptions for all sectors of society and for different world evolutions, consisting of a very useful tool for discussing adaptation and structuring thought in this context. However, their use is dependent on a great deal of interaction and proximity to stakeholders as they can be challenging to understand. This involvement effort is even more critical when one seeks to use the SSP/SPA scenarios for short/medium term planning exercises and identifies some mismatch between Portugal's historical trends over the last decade and those projected in each existing SSPs for that period.

The Eurostat scenarios and, consequently, those of the Ageing Report make a single basic assumption: the European Union will move towards integration, implying relatively identical national population patterns. The United Nations and INE scenarios also incorporate assumptions based on observations of historical demographic trends. However, the former scenarios are created with methodologies that must be adaptable to all countries regardless of data quality and availability. In contrast, INE's scenarios use methodologies best suited to the Portuguese context. In addition, INE is the official source and national authority of population data for Portugal.

The Carbon Neutrality Roadmap 2050 (RNC2050) projections are closer to the INE projections than the other demographic and socioeconomic scenarios identified in this report (the UN, Eurostat, and SSPs). This is because the base data used by the RNC 2050 also consist of INE studies (although an older version).

We propose using the INE's demographic scenarios up to 2080 (or equivalent until 2100) since we consider that they best reflect the historical trends for Portugal and integrate those trends into future projections. This is based on the different analyses carried out. These comprise comparability between projections, objectives of the RNA2100, consultation of various entities involved in the RNA2100, and consultation of the National Statistics Institute. Among the projections available, it is also suggested to use the central scenario since it will be the most probable and, in this sense, the most appropriate to be used in the scope of a short-, medium- and long-term planning exercise.

Regarding **economic projections**, the sources of information with medium- or long-term indicators for Portugal are relatively scarce or even non-existent if the focus is only on national sources. Considering the information gathered, the same difficulties of applicability were noted in the projections coming from the SSP/SPA scenarios, referred to in the context of demographic projections. Nevertheless, it is worth to mention the consistency observed between the data produced for each SSP and the respective storyline, which emphasizes the potential for the development of new scientific knowledge based on these scenarios. In addition to these scenarios, the European Union's Department of Economic and Social Affairs also projected some macroeconomic variables up to 2070. These macroeconomic variables are estimated based on demographic projections prepared by Eurostat, which imply the integration of the assumptions of that scenario.

From the analysis carried out, it was concluded that the economic information obtained from a given source cannot be made compatible with demographic data from other sources because this process would compromise the internal consistency of the assumptions embedded in each socio-economic projection. This means that either the socio-economic data from the SSP/SPA scenarios or those from Eurostat and European Union Department of Economic and Social Affairs would be used. Therefore, and because of different interactions between the members of the consortium, it was decided that **the economic projections necessary for this exercise will be prepared by Banco de Portugal** (within the scope of WP6) to ensure consistency between demographics and economic data.

Finally, and regarding **land use projections**, it was found that the only projections available until the end of the century are the SSP/SPA scenarios. As expected, these projections are consistent with the narratives/storylines of each scenario, making it possible to analyze global or regional trends considering alternative futures that arise from each storyline.

However, the available information cannot be used within the scope of the project, as the geographic accuracy of land use is still far from accurately representing the reality observed in the country for the present (and consequently in the future), lacking further research developments. Therefore, and after different interactions, it was decided by the consortium **not to use land use projections** in the project (and in the impact modeling exercises considering climate change scenarios) but **static land use**.

4.1 Socioeconomic scenarios used throughout the project (WP3B)

The demographic projections used in the National Adaptation Roadmap 2100 (RNA2100) result from projections made by the National Institute of Statistics, adopting the central scenario that is considered the most probable in this exercise. The following tables summarize the central demographic projections for Portugal and respective NUTS II to be used within the RNA2100. Table 13 summarizes the resident population projections, Table 14 the projections of the annual rate of change of the resident population,

Table 15 the projections of the aging index, Table 16 the projections of the youth dependency index,

Table 18 the projections of the elderly dependency index,

Table 18 the projections of the total dependency index and Table 19 the projections of average life expectancy at birth.

Table 13. Projections of the resident population in Portugal and respective NUTS II regions (central scenario). Source: INE, Projeções da população residente. Source: INE (2020)

Region/year	2020	2030	2040	2050	2060	2070	2080
Portugal	**10,330,240**	**10,295,824**	**10,046,681**	**9,647,698**	**9,157,001**	**8,647,928**	**8,216,015**
Norte	3,577,042	3,511,403	3,350,921	3,104,455	2,812,059	2,518,563	2,255,131
Centro	2,204,511	2,134,273	2,037,975	1,913,563	1,772,541	1,634,518	1,515,938
AM Lisboa	2,902,442	2,993,084	3,038,194	3,069,604	3,084,387	3,081,029	3,096,272
Alentejo	704,146	685,394	653,893	615,181	572,802	531,428	495,189
Algarve	445,031	474,725	487,086	495,887	503,298	510,152	519,766
RA Açores	242,532	245,050	238,092	225,515	209,125	190,405	170,969
RA Madeira	254,536	251,895	240,520	223,493	202,789	181,833	162,750

Table 14. Projections of the annual rate of change of the population in Portugal and respective NUTS II regions (central scenario). Database source: INE, Projeções da população residente. Source: INE (2020)

Region/year	2020-2030	2030-2040	2040-2050	2050-2060	2060-2070	2070-2080
Portugal	**-0.03**	**-0.24**	**-0.40**	**-0.51**	**-0.56**	**-0.50**
Norte	-0.18	-0.46	-0.74	-0.94	-1.04	-1.05
Centro	-0.32	-0.45	-0.61	-0.74	-0.78	-0.73
AM Lisboa	0.31	0.15	0.10	0.05	-0.01	0.05
Alentejo	-0.27	-0.46	-0.59	-0.69	-0.72	-0.68
Algarve	0.67	0.26	0.18	0.15	0.14	0.19
RA Açores	0.10	-0.28	-0.53	-0.73	-0.90	-1.02
RA Madeira	-0.10	-0.45	-0.71	-0.93	-1.03	-1.05

Table 15. Projections of the aging index of the resident population in Portugal and respective NUTS II regions (central scenario). Source: INE, Projeções da população residente. Source: INE (2020)

Region/year	2020	2030	2040	2050	2060	2070	2080
Portugal	**167.7**	**214.5**	**258.9**	**297.2**	**308**	**305.9**	**300.3**
Norte	172.6	241.4	310.2	381.6	414.8	421.6	424
Centro	210.5	267.8	315.5	366.5	385.8	385.7	380.7
AM Lisboa	141	168.7	197.4	214.7	216.8	214.4	213.9
Alentejo	210.2	245.4	278.2	319.8	331.7	331.2	329

Region/year	2020	2030	2040	2050	2060	2070	2080
Algarve	147.4	165.9	190	213.5	211.5	206.9	204.4
RA Açores	100.4	152.4	210	286.3	343.5	372.9	390.4
RA Madeira	136	206.1	274.3	361.5	415.1	428.2	429.3

Table 16. Youth dependency index projections for Portugal and respective NUTS II regions (central scenario). Source: INE, Projeções da população residente. Source: INE (2020)

Region/year	2020	2030	2040	2050	2060	2070	2080
Portugal	20.9	20.8	22.1	22.5	22.4	23.7	24.1
Norte	18.8	18.9	20	19.5	19.5	21.3	21.4
Centro	18.8	18.7	20	20	19.7	21.2	21.6
AM Lisboa	25.4	24.6	25.4	26.9	26.3	26.3	26.8
Alentejo	19.8	20.1	21.7	21.8	21.6	23.1	23.2
Algarve	23.4	24.1	25.9	26.3	26.4	27.4	27.3
RA Açores	21.7	20.3	20.1	19.6	19.9	21	21.1
RA Madeira	18.4	17.8	19.2	18.5	18.3	20.7	20.8

Table 17. Projections of the old-age dependency ratio in Portugal and respective NUTS II regions (central scenario). Source: INE, Projeções da população residente. Source: INE (2020)

Region/year	2020	2030	2040	2050	2060	2070	2080
Portugal	35.1	44.7	57.1	66.8	69.1	72.3	72.4
Norte	32.4	45.7	62.1	74.5	80.8	89.7	90.6
Centro	39.6	50	63.1	73.2	76.2	81.8	82.2
AM Lisboa	35.8	41.5	50.1	57.7	57	56.3	57.3
Alentejo	41.7	49.2	60.3	69.8	71.6	76.4	76.5
Algarve	34.5	40	49.2	56.2	55.8	56.7	55.9
RA Açores	21.8	30.9	42.3	56.2	68.5	78.4	82.5
RA Madeira	25	36.7	52.7	66.8	76	88.4	89.4

Table 18. Projections of the total dependency ratio in Portugal and respective NUTS II regions (central scenario). Source: INE, Projeções da população residente. Source: INE (2020)

Region/year	2020	2030	2040	2050	2060	2070	2080
Portugal	56	65.5	79.2	89.3	91.6	96	96.5
Norte	51.2	64.6	82.2	94	100.2	110.9	111.9
Centro	58.4	68.7	83	93.2	95.9	103.1	103.8
AM Lisboa	61.2	66.1	75.6	84.6	83.4	82.6	84.1
Alentejo	61.5	69.3	81.9	91.6	93.2	99.4	99.7
Algarve	58	64	75.1	82.5	82.2	84.2	83.2
RA Açores	43.6	51.2	62.4	75.9	88.4	99.4	103.6
RA Madeira	43.4	54.5	72	85.3	94.3	109.1	110.2

Table 19. Projections of average life expectancy at birth in Portugal and respective NUTS II regions (central scenario). Source: INE, Projeções da população residente. Source: INE (2020)

Region/year	2020		2030		2040		2050		2060		2070		2080	
	M	W	M	W	M	W	M	W	M	W	M	W	M	W
Portugal	78.62	84.58	80.49	86.35	80.63	87.25	83.75	89.46	85.23	90.85	86.62	92.13	87.92	93.30
Norte	78.81	84.62	80.57	86.26	82.17	87.96	83.63	89.12	84.99	90.38	86.25	91.53	87.41	92.57
Centro	79.10	84.81	80.86	86.41	82.17	87.76	83.90	89.21	85.25	90.44	86.49	91.57	87.63	92.59
AM Lisboa	78.56	84.52	80.42	86.18	82.45	87.87	83.66	89.05	85.10	90.31	86.44	91.46	87.66	92.50
Alentejo	78.53	84.37	80.35	86.04	82.11	87.68	83.51	88.93	84.92	90.21	86.22	91.37	87.42	92.42
Algarve	77.41	83.98	79.45	85.82	82	87.55	82.92	88.87	84.41	90.16	85.81	91.34	87.14	92.50
RA Açores	74.94	82.16	76.94	84.03	81.27	87.43	80.49	87.22	82.05	88.61	83.49	89.86	84.86	90.98
RA Madeira	75.13	82.10	77.13	84.02	78.79	85.70	80.63	87.25	82.19	88.63	83.64	89.85	84.98	91.01

5. References

Alcamo, J., Bouwman, A., Edmonds, J., Grubler, A., Morita, T., Sugandhy, A., 1995a. An Evaluation of the IPCC IS92 Emission Scenarios, in: Climate Change 1994. Radiative Forcing of Climate Change and an Evaluation of the IPCC 1992 IS92 Emission Scenarios. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Alcamo, J., Bouwman, A., Edmonds, J., Grubler, A., Morita, T., Sugandhy, A., 1995b. An Evaluation of the IPCC IS92 Emission Scenarios, in: Climate Change 1994. Radiative Forcing of Climate Change and an Evaluation of the IPCC 1992 IS92 Emission Scenarios. Intergovernmental Panel on Climate Change. IIASA Research Report (Reprint), IIASA, Laxenburg, Austria: RR-95-010, pp. 247–304.

APA, 2019. Roadmap for Carbon Neutrality 2050 (RNC2050): Long-Term Strategy for Carbon Neutrality of the Portuguese Economy.

APA, 2012. Roteiro Nacional de Baixo Carbono 2050 - Análise técnica das opções de transição para uma economia de baixo carbono competitiva em 2050.

Barata, P.M., Pinto, B.V., Sousa, R., Aguiar-Conraria, L., Alexandre, F., 2018. P2.3 Cenários socioeconómicos de evolução do país no horizonte 2050. RNC 2050 – Roteiro para a Neutralidade Carbónica 2050 477.

Bolin, B., 2007a. A History of the Science and Politics of Climate Change: The Role of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

Bolin, B., 2007b. A History of the Science and Politics of Climate Change: The Role of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

Calvin, K., Bond-Lamberty, B., Clarke, L., Edmonds, J., Eom, J., Hartin, C., Kim, S., Kyle, P., Link, R., Moss, R., McJeon, H., Patel, P., Smith, S., Waldhoff, S., Wise, M., 2017. The SSP4: A world of deepening inequality. Global Environmental Change 42, 284–296. https://doi.org/10.1016/J.GLOENVCHA.2016.06.010

CAT, 2021. Global emissions time series [Dataset], Climate Action Tracker.

Chen, M., Vernon, C.R., Graham, N.T., Hejazi, M., Huang, M., Cheng, Y., Calvin, K., 2020. Global land use for 2015–2100 at 0.05° resolution under diverse socioeconomic and climate scenarios. Scientific Data 2020 7:1 7, 1–11. https://doi.org/10.1038/s41597-020-00669-x

Cloy, J.M., Smith, K.A., 2018. Greenhouse Gas Sources and Sinks, Encyclopedia of the Anthropocene. Elsevier Inc. https://doi.org/10.1016/B978-0-12-809665-9.09961-4

Cobb, C.W., Douglas, P.H., 1928. A Theory of Production. American Economic Review. 18, 139–165.

Costa, H., de Rigo, D., Libertà, G., Houston Durrant, T., San-Miguel-Ayanz, J., 2020. European wildfire danger and vulnerability in a changing climate: towards integrating risk dimensions. Luxemburg. https://doi.org/10.2760/46951

Costanza, R., 2014. Time to leave GDP behind. Nature 505, 283–285. https://doi.org/10.1038/505283a

Dellink, R., Chateau, J., Lanzi, E., Magné, B., 2017a. Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change 42, 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004

Dellink, R., Chateau, J., Lanzi, E., Magné, B., 2017b. Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change 42, 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004

Doelman, J.C., Stehfest, E., Tabeau, A., van Meijl, H., Lassaletta, L., Gernaat, D.E.H.J., Hermans, K., Harmsen, M., Daioglou, V., Biemans, H., van der Sluis, S., van Vuuren, D.P., 2018. Exploring SSP land-use dynamics using the IMAGE model: Regional and gridded scenarios of land-use change and land-based climate change mitigation. Global Environmental Change 48, 119–135. https://doi.org/10.1016/j.gloenvcha.2017.11.014

EC, 2021. The 2021 Ageing Report: Economic and Budgetary Projections for the EU Member States (2019-2070). Commission Economic, Economic Policy Committee European Economy Institutional Papers, p. 398. https://doi.org/10.2765/84455

EC, 2020. The 2021 ageing report : underlying assumptions and projection methodologies. Brussels.

EEA, 2022. Global and European temperatures [WWW Document]. URL https://www.eea.europa.eu/ims/global-and-european-temperatures (accessed 6.26.22).

EEA, 2017. Climate change, impacts and vulnerability in Europe 2016 - An indicator-based report. https://doi.org/citeulike-article-id:14262052 doi: 10.2800/534806

Eurostat, 2020. Methodology of the Eurostat population projections 2019-based (EUROPOP2019). Luxembourg.

Fricko, O., Havlik, P., Rogelj, J., Klimont, Z., Gusti, M., Johnson, N., Kolp, P., Strubegger, M., Valin, H., Amann, M., Ermolieva, T., Forsell, N., Herrero, M., Heyes, C., Kindermann, G., Krey, V., McCollum, D.L., Obersteiner, M., Pachauri, S., Rao, S., Schmid, E., Schoepp, W., Riahi, K., 2017. The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century. Global Environmental Change 42, 251–267. https://doi.org/10.1016/j.gloenvcha.2016.06.004

Fujimori, S., Hasegawa, T., Masui, T., Takahashi, K., Herran, D.S., Dai, H., Hijioka, Y., Kainuma, M., 2017. SSP3: AIM implementation of Shared Socioeconomic Pathways. Global Environmental Change 42, 268–283. https://doi.org/10.1016/j.gloenvcha.2016.06.009

Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., Andrew, R.M., Ciais, P., Jackson, R.B., Jones, C.D., Kraxner, F., Nakicenovic, N., le Quéré, C., Raupach, M.R., Sharifi, A., Smith, P., Yamagata, Y., 2014. Betting on negative emissions. Nature Climate Change 4, 850–853. https://doi.org/10.1038/nclimate2392

GCP, 2020. Data supplement to the Global Carbon Budget 2020 (Version 1.0) [Dataset]. https://doi.org/doi.org/10.18160/gcp-2020

Gidden, M.J., Riahi, K., Smith, S.J., Fujimori, S., Luderer, G., Kriegler, E., van Vuuren, D.P., van den Berg, M., Feng, L., Klein, D., Calvin, K., Doelman, J.C., Frank, S., Fricko, O., Harmsen, M., Hasegawa, T., Havlik, P., Hilaire, J., Hoesly, R., Horing, J., Popp, A., Stehfest, E., Takahashi, K., 2019a. Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. Geoscientific Model Development 12, 1443–1475. https://doi.org/10.5194/gmd-12-1443-2019

Gidden, M.J., Riahi, K., Smith, S.J., Fujimori, S., Luderer, G., Kriegler, E., van Vuuren, D.P., van den Berg, M., Feng, L., Klein, D., Calvin, K., Doelman, J.C., Frank, S., Fricko, O., Harmsen, M., Hasegawa, T., Havlik, P., Hilaire, J., Hoesly, R., Horing, J., Popp, A., Stehfest, E., Takahashi, K., 2019b. Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. Geoscientific Model Development 12, 1443–1475. https://doi.org/10.5194/gmd-12-1443-2019

Gidden, M.J., Riahi, K., Smith, S.J., Fujimori, S., Luderer, G., Kriegler, E., van Vuuren, D.P., van den Berg, M., Feng, L., Klein, D., Calvin, K., Doelman, J.C., Frank, S., Fricko, O., Harmsen, M., Hasegawa, T., Havlik, P., Hilaire, J., Hoesly, R., Horing, J., Popp, A., Stehfest, E., Takahashi, K., 2018. Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. Geoscientific Model Development Discussions 1–42. https://doi.org/10.5194/gmd-2018-266

Girod, B., Wiek, A., Mieg, H., Hulme, M., 2009. The evolution of the IPCC's emissions scenarios. Environ Sci Policy 12, 103–118. https://doi.org/10.1016/j.envsci.2008.12.006

Hulme, M., 2016. Weathered: cultures of climate. SAGE Publications Ltd, London.

Hurtt, G.C., Chini, L., Sahajpal, R., Frolking, S., Bodirsky, B.L., Calvin, K., Doelman, J.C., Fisk, J., Fujimori, S., Klein Goldewijk, K., Hasegawa, T., Havlik, P., Heinimann, A., Humpenöder, F., Jungclaus, J., Kaplan, J.O., Kennedy, J., Krisztin, T., Lawrence, D., Lawrence, P., Ma, L., Mertz, O., Pongratz, J., Popp, A., Poulter, B., Riahi, K., Shevliakova, E., Stehfest, E., Thornton, P., Tubiello, F.N., van Vuuren, D.P., Zhang, X., 2020. Harmonization of global land use change and management for the period 850–2100 (LUH2) for CMIP6. Geoscientific Model Development 13, 5425–5464. https://doi.org/10.5194/gmd-13-5425-2020

Hurtt, G.C., Chini, L.P., Frolking, S., Betts, R.A., Feddema, J., Fischer, G., Fisk, J.P., Hibbard, K., Houghton, R.A., Janetos, A., Jones, C.D., Kindermann, G., Kinoshita, T., Klein Goldewijk, K., Riahi, K., Shevliakova, E., Smith, S., Stehfest, E., Thomson, A., Thornton, P., van Vuuren, D.P., Wang, Y.P., 2011. Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. Climatic Change 109, 117–161. https://doi.org/10.1007/s10584-011-0153-2

IAC, 2010. Climate change assessments: Review of the processes and procedures of the IPCC.

INE, 2020a. Projeções de População Residente 2018-2080 - Informação à Comunicação Social.

INE, 2020b. Projeções de População Residente 2018-2080 - Informação à Comunicação Social.

INE, 2017a. Projeções de População Residente. Documento Metodológico, Versão 3.0.

INE, 2017b. Projeções de População Residente. Documento Metodológico, Versão 3.0.

INE, 2017c. Projeções da População Residente 2015-2080.

IPCC, 2022a. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. In Press. .

IPCC, 2022b. Climate Change 2022: Impacts, Adaptation and Vulnerability: Summary for Policymakers.

IPCC, 2022c. Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the IPCC Sixth Assessment Report, Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926

IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Cambridge University Press.

IPCC, 2018. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change. Geneva, Switzerland.

IPCC, 2014a. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

IPCC, 2014b. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

IPCC, 2014c. Climate Change 2014 Mitigation of Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://doi.org/10.1017/CBO9781107415324

IPCC, 2007a. Climate Change 2007: Synthesis Report. Intergovernmental Panel on Climate Change.

IPCC, 2007b. Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies: Technical Summary. Noordwijkerhout, The Netherlands, 19–21 September, 2007.

IPCC, 2007c. Climate Change 2007: Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change.

IPCC, 2007d. Climate Change 2007: Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change.

IPCC, 2007e. Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies: Technical Summary. Noordwijkerhout, The Netherlands, 19–21 September, 2007.

IPCC, 2006. Report of the 25th session of the IPCC (Port Louis, Mauritius, 26-28 April 2006). Port Louis, Mauritius.

IPCC, 2005. IPCC Expert meeting on emission scenarios: meeting report. 12-14 January, Washingto DC. https://doi.org/10.1007/BF02986817

IPCC, 2001a. Climate Change 2001. Working Group II: Impacts, Adaptation and Vulnerability.

IPCC, 2001b. Climate Change 2001. Working Group II: Impacts, Adaptation and Vulnerability.

IPCC, 2001c. Climate Change 2001. Working Group I: The Scientific Basis.

IPCC, 2000. IPCC Special Report: Emission Scenarios. Summary for Policymakers. A Special Report of IPCC Working Group III.

IPCC, 1996a. Report of the Twelfth Session of the IPCC. Mexico City, 11-13 September, 1996.

IPCC, 1996b. Report of the Twelfth Session of the IPCC. Mexico City, 11-13 September, 1996.

IPCC, 1995. Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses (WG2). New York.

IPCC, 1992. Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment. University Press, Cambridge, UK.

IPCC, 1991a. Report of the 6th Session of the IPCC [WWW Document].

IPCC, 1991b. Report of the 6th Session of the IPCC [WWW Document]. URL https://www.ipcc.ch/meetings/session06/sixth-session-report.pdf

IPCC, 1990a. Climate Change: The IPCC Response Strategies, Working Group III.

IPCC, 1990b. Climate change: The IPCC scientific assessment. Cambridge University Press, Cambridge, New York, Port Chester, Melbourne, Sydney.

IPCC, 1990c. Climate Change: The IPCC Response Strategies, Working Group III.

IPCC, 1990d. Emissions scenarios: Appendix report of the Expert Group on Emission Scenarios, in: Tirpak, D., Velinga, P., Swart, R., Elzen, M. den, Rotmans, J. (Eds.), Climate Change: The IPCC Response Strategies. The Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC), p. 231.

IPCC, 1990e. Climate Change: The IPCC Response Strategies, Working Group III.

IPCC, 1990f. Emissions scenarios: Appendix report of the Expert Group on Emission Scenarios, in: Tirpak, D., Velinga, P., Swart, R., Elzen, M. den, Rotmans, J. (Eds.), Climate Change: The IPCC Response Strategies. The Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC), p. 231.

IPCC, 1990g. Climate change: The IPCC scientific assessment. Cambridge University Press, Cambridge, New York, Port Chester, Melbourne, Sydney.

IPCC, 1989. Report of the Second Session of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC). World Meteorological Organization (WMO) & United Nations Environment Programme (UNEP).

KC, S., Lutz, W., 2017. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change 42, 181–192. https://doi.org/10.1016/j.gloenvcha.2014.06.004

Kebede, A.S., Nicholls, R.J., Allan, A., Arto, I., Cazcarro, I., Fernandes, J.A., Hill, C.T., Hutton, C.W., Kay, S., Lázár, A.N., Macadam, I., Palmer, M., Suckall, N., Tompkins, E.L., Vincent, K., Whitehead, P.W., 2018. Applying the global RCP–SSP–SPA scenario framework at sub-national scale: A multi-scale and participatory scenario approach. Science of The Total Environment 635, 659–672. https://doi.org/10.1016/j.scitotenv.2018.03.368

Klein, R.J.T., Schipper, E.L.F., Dessai, S., 2005. Integrating mitigation and adaptation into climate and development policy: Three research questions. Environmental Science and Policy 8, 579–588. https://doi.org/10.1016/j.envsci.2005.06.010

Kok, K., Pedde, S., Gramberger, M., Harrison, P.A., Holman, I.P., 2019. New European socio-economic scenarios for climate change research: operationalising concepts to extend the shared socio-economic pathways. Regional Environmental Change 19, 643–654. https://doi.org/10.1007/s10113-018-1400-0

Koutroulis, A.G., Papadimitriou, L.V., Grillakis, M.G., Tsanis, I.K., Warren, R., Betts, R.A., 2019. Global water availability under high-end climate change: A vulnerability based assessment. Global and Planetary Change 175, 52–63. https://doi.org/10.1016/j.gloplacha.2019.01.013

Kriegler, E., Bauer, N., Popp, A., Humpenöder, F., Leimbach, M., Strefler, J., Baumstark, L., Bodirsky, B.L., Hilaire, J., Klein, D., Mouratiadou, I., Weindl, I., Bertram, C., Dietrich, J.-P., Luderer, G., Pehl, M., Pietzcker, R., Piontek, F., Lotze-Campen, H., Biewald, A., Bonsch, M., Giannousakis, A., Kreidenweis, U., Müller, C., Rolinski, S., Schultes, A., Schwanitz, J., Stevanovic, M., Calvin, K., Emmerling, J., Fujimori, S., Edenhofer, O., 2017. Fossil-fueled development (SSP5): An energy and resource intensive scenario for the 21st century. Global Environmental Change 42, 297–315. https://doi.org/10.1016/J.GLOENVCHA.2016.05.015

Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K.L., Kram, T., Riahi, K., Winkler, H., van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared climate policy assumptions. Climatic Change 122, 401–414. https://doi.org/10.1007/s10584-013-0971-5

Lahn, B., 2018. In the light of equity and science: scientific expertise and climate justice after Paris. International Environmental Agreements: Politics, Law and Economics 18, 29–43. https://doi.org/10.1007/s10784-017-9375-8

le Quéré, 2004. The global carbon cycle: integrating humans, climate, and the natural world. Island Press, Washington, DC.

Leggett, J., Pepper, W.J., Swart, R.J., Edmonds, J., Meira Filho, L.G., Mintzer, I., Wang, M.X., Wasson, J., 1992a. Emissions scenarios for the IPCC: an update, in: Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment. pp. 69–95.

Leggett, J., Pepper, W.J., Swart, R.J., Edmonds, J., Meira Filho, L.G., Mintzer, I., Wang, M.X., Wasson, J., 1992b. Emissions scenarios for the IPCC: an update. Climate change 1992: the supplementary report to the IPCC scientific assessment 69–95.

Liao, W., Liu, X., Xu, X., Chen, G., Liang, X., Zhang, H., Li, X., 2020. Projections of land use changes under the plant functional type classification in different SSP-RCP scenarios in China. Science Bulletin 65, 1935–1947. https://doi.org/10.1016/j.scib.2020.07.014

Marangoni, G., Tavoni, M., Bosetti, V., Borgonovo, E., Capros, P., Fricko, O., Gernaat, D.E.H.J., Guivarch, C., Havlik, P., Huppmann, D., Johnson, N., Karkatsoulis, P., Keppo, I., Krey, V., Ó Broin, E., Price, J., van Vuuren, D.P., 2017. Sensitivity of projected long-term CO_2 emissions across the Shared Socioeconomic Pathways. Nature Climate Change 7, 113–117. https://doi.org/10.1038/nclimate3199

McGrath, M., 2016. Climate change: “Monumental” deal to cut HFCs, fastest growing greenhouse gases [WWW Document]. BBC News. URL https://www.bbc.com/news/science-environment-37665529 (accessed 11.24.20).

Meadows, D.H., Meadows, D.L., Randers, J., Behrens III, W.W., 1972. The Limits to Growth: A Report for The Club of Rome’s Project on the Predicament of Mankind. Potomac Associates, New York.

Moss, Richard H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–756. https://doi.org/10.1038/nature08823

Moss, Richard H, Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747–756. https://doi.org/10.1038/nature08823

Nakicenovic, N., Swart, R., 2000a. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, UK.

Nakicenovic, N., Swart, R., 2000b. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, UK.

Ngo, H.T., Guèze, M., Agard Trinidad, J., Arneth, A., Balvanera, P., Brauman, K., Watson, R., Baste, I., Larigauderie, A., Leadley, P., Pascual, U., Baptiste, B., Demissew, S., Dziba, L., Erpul, G., Fazel, A., Fischer, M., María Hernández, A., Karki, M., Mathur, V., Pataridze, T., Sousa Pinto, I., Stenseke, M., Török, K., Vilá, B., Carneiro da Cunha, M., Mace, G., Mooney, H., 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services-unedited advance version Members of the management committee who provided guidance for the production of this assessment Overall review editors.

NRC, 2010. Understanding Climate’s Influence on Human Evolution. National Academies Press, Washington, D.C. https://doi.org/10.17226/12825

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2017a. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2017b. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Climatic Change 122, 387–400. https://doi.org/10.1007/s10584-013-0905-2

O'Neill, B.C., Tebaldi, C., van Vuuren, D.P., Eyring, V., Friedlingstein, P., Hurtt, G., Knutti, R., Kriegler, E., Lamarque, J.-F., Lowe, J., Meehl, G.A., Moss, R., Riahi, K., Sanderson, B.M., 2016. The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. Geoscientific Model Development 9, 3461–3482. https://doi.org/10.5194/gmd-9-3461-2016

Parikh, J.K., 1992. IPCC strategies unfair to the South. Nature. https://doi.org/10.1038/360507a0

Pedersen, J.S.T., Duarte Santos, F., van Vuuren, D., Gupta, J., Coelho, R.E., Aparício, B.A., Swart, R., 2021. An assessment of the performance of scenarios against historical global emissions for IPCC reports. Global Environmental Change 66, 102199. https://doi.org/10.1016/j.gloenvcha.2020.102199

Pedersen, J.S.T., Vuuren, D.P. van, Aparício, B.A., Swart, R., Gupta, J., Santos, F.D., 2020. Variability in historical emissions trends suggests a need for a wide range of global scenarios and regional analyses. Communications Earth & Environment 1–7. https://doi.org/10.1038/s43247-020-00045-y

Pedersen, J.T.S., van Vuuren, D., Gupta, J., Santos, F.D., Edmonds, J., Swart, R., 2022a. IPCC emission scenarios: How did critiques affect their quality and relevance 1990–2022? Global Environmental Change 75, 102538. https://doi.org/10.1016/J.GLOENVCHA.2022.102538

Pedersen, J.T.S., Vuuren, D. van, Gupta, J., Santos, F.D., Edmonds, J., Swart, R., 2022b. IPCC emission scenarios: How did critiques affect their quality and relevance 1990–2022? Global Environmental Change.

Pepper, W.J., Leggett, R.J., Swart, R.J., Wasson, J., Edmonds, J., Mintzer, I., 1992a. Emission Scenarios for the IPCC. An Update. Assumptions, Methodology, and Results. Washington, D.C.

Pepper, W.J., Leggett, R.J., Swart, R.J., Wasson, J., Edmonds, J., Mintzer, I., 1992b. Emission Scenarios for the IPCC. An Update. Assumptions, Methodology, and Results. Washington, D.C.

Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietrich, J.P., Doelmann, J.C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weindl, I., Wise, M., Kriegler, E., Lotze-Campen, H., Fricko, O., Riahi, K., Vuuren, D.P. van, 2017a. Land-use futures in the shared socio-economic pathways. Global Environmental Change 42, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002

Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietrich, J.P., Doelmann, J.C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weindl, I., Wise, M., Kriegler, E., Lotze-

Campen, H., Fricko, O., Riahi, K., Vuuren, D.P. van, 2017b. Land-use futures in the shared socio-economic pathways. Global Environmental Change 42, 331–345. https://doi.org/10.1016/J.GLOENVCHA.2016.10.002

Raskin, P., Monks, F., Ribeiro, T., van Vuuren, D., Zurek, M., 2005. Global Scenarios in Historical Perspective [WWW Document]. Ecosystems and Human Well-Being: Scenarios: Findings of the Scenarios Working Group. URL https://pdfs.semanticscholar.org/780d/43ae4d93304b3d4d31f229656fd1d2aa02d5.pdf

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017a. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017b. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Ritchie, H., Roser, M., 2018. CO_2 and other Greenhouse Gas Emissions [WWW Document]. Our World in Data. URL https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions (accessed 4.24.18).

Schwalm, C.R., Glendon, S., Duffy, P.B., 2020. RCP8.5 tracks cumulative CO_2 emissions. Proceedings of the National Academy of Sciences 117, 202007117. https://doi.org/10.1073/pnas.2007117117

Tamura, M., Kumano, N., Yotsukuri, M., Yokoki, H., 2019. Global assessment of the effectiveness of adaptation in coastal areas based on RCP/SSP scenarios. Climatic Change 152, 363–377. https://doi.org/10.1007/s10584-018-2356-2

UN, 2019. World Population Prospects 2019: Methodology of the United Nations population estimates and projections. New York.

UN, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. Kyoto.

UN, 1989. Montreal Protocol on Substances that Deplete the Ozone Layer Montreal, 16 September 1987 [WWW Document]. United Nations Treaty Collection. URL https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-2-a&chapter=27&lang=en

UN, 1956. Manual III. Methods for Population Projections by Sex and Age.

UNEP, 2019. Emissions Gap Report 2019.

UNEP, 2016. The Kigali Amendment (2016): The amendment to the Montreal Protocol agreed by the Twenty-Eighth Meeting of the Parties (Kigali, 10-15 October 2016) [WWW Document]. Ozone Secretariat. URL https://ozone.unep.org/treaties/montreal-protocol/amendments/kigali-amendment-2016-amendment-montreal-protocol-agreed (accessed 11.24.20).

UNFCCC, 2015. Adoption of the Paris agreement. United Nations Framework Convention on Climate Change, Bonn, Germany.

UNFCCC/COP, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. CONFERENCE OF THE PARTIES, Third session, Kyoto, Japan. 1-10 December 1997.

van Vuuren, D.P., Carter, T.R., 2014. Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old. Clim. Change 122, 415–429. https://doi.org/10.1007/s10584-013-0974-2

van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K., 2011a. The representative concentration pathways: an overview. Climatic Change 109, 5–31. https://doi.org/10.1007/s10584-011-0148-z

van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K., 2011b. The representative concentration pathways: an overview. Climatic Change 109, 5–31. https://doi.org/10.1007/s10584-011-0148-z

van Vuuren, D.P., Kok, M.T.J., Girod, B., Lucas, P.L., de Vries, B., 2012a. Scenarios in Global Environmental Assessments: Key characteristics and lessons for future use. Global Environmental Change 22, 884–895. https://doi.org/10.1016/J.GLOENVCHA.2012.06.001

van Vuuren, D.P., Kriegler, E., O'Neill, B.C., Ebi, K.L., Riahi, K., Carter, T.R., Edmonds, J., Hallegatte, S., Kram, T., Mathur, R., Winkler, H., 2014. A new scenario framework for Climate Change Research: Scenario matrix architecture. Climatic Change 122, 373–386. https://doi.org/10.1007/s10584-013-0906-1

van Vuuren, D.P., Riahi, K., Moss, R., Edmonds, J., Thomson, A., Nakicenovic, N., Kram, T., Berkhout, F., Swart, R., Janetos, A., Rose, S.K., Arnell, N., 2012b. A proposal for a new scenario framework to support research and assessment in different climate research communities. Global Environmental Change 22, 21–35. https://doi.org/10.1016/J.GLOENVCHA.2011.08.002

van Vuuren, D.P., Stehfest, E., Gernaat, D.E.H.J., Doelman, J.C., van den Berg, M., Harmsen, M., de Boer, H.S., Bouwman, L.F., Daioglou, V., Edelenbosch, O.Y., Girod, B., Kram, T., Lassaletta, L., Lucas, P.L., van Meijl, H., Müller, C., van Ruijven, B.J., van der Sluis, S., Tabeau, A., 2017. Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. Global Environmental Change 42, 237–250. https://doi.org/10.1016/j.gloenvcha.2016.05.008

Ward, J.D., Sutton, P.C., Werner, A.D., Costanza, R., Mohr, S.H., Simmons, C.T., 2016. Is Decoupling GDP Growth from Environmental Impact Possible? PLOS ONE 11, e0164733. https://doi.org/10.1371/journal.pone.0164733

Zachariah, K.C., Vu, M.T., 1987. 1988: World Population Projections 1987-88 Edition. Johns Hopkins University Press, Baltimore, Maryland.

6. Annex

6.1 Annex I – Key IAM models

Table 20. General description of different IAM Marangoni et al. (2017)

Model	Description
GEM-E3-ICCS24	A general equilibrium model that emphasizes market instruments analysis concerning energy-related environmental policies (e.g., taxes, subsidies, regulations, emission allowances, and others) with detail sufficient to evaluate national, sectoral, and global policies. Emphasis is also placed on assessing the distributional consequences of policies and programs, including social equity, employment, and cohesion in less developed regions.
IMACLIM	A recursive dynamics hybrid model, combining a general equilibrium approach with explicitly technological modules. Its purpose is to study the interactions between energy systems and the economy to assess the feasibility of low-carbon development strategies and the transition towards a carbon-neutral future.
IMAGE	A recursive dynamics model, described as a geographically specific assessment. It is an IAM that focuses on a detailed representation of processes relevant to human use of energy, soils, and water resources concerning relevant environmental processes. The purposes of this model are to i) analyze the interactions between human development and the natural environment to gain a better understanding of global environmental change; ii) identify response strategies to global environmental change based on options assessment, and iii) indicate key linkages and levels of uncertainty regarding global environmental change processes.
MESSAGE-GLOBIOM	Model integrating MESSAGE (energy-engineering model) and GLOBIOM (land use model) into a consistent, integrated assessment framework. To consider general equilibrium effects, a link is made to MACRO (aggregate macroeconomics model).
TIAM-UCL	A partial equilibrium model focused on energy systems. It uses the TIMES modeling platform, expanded by representing emissions from non-energy sources and a simple climate model. Scenario-based simulations maximize the discounted total of consumer and supplier surpluses over the model horizon, considering constraints (e.g., energy demand that must be secured, availability of energy resources, etc.).
WITCH-GLOBIOM	A hybrid model of optimal economic growth. Includes a bottom-up energy sector and a simple climate model embedded in a game theory setup. The impacts of climate policies on global and regional economic systems are assessed, and information is provided on the optimal responses of these economies to climate change. The positive externalities of learning from experience and research on technological change in the energy sector are also considered.

6.2 ANEXO II – Socio-economic scenarios within the IPCC context

There are so far four generations of socio-economic and emissions scenarios informing the IPCC Assessment Reports (Ars) and each of the three IPCC working groups, chronologically subsequent and with some temporal overlaps. These scenario generations are represented in Figure 47.

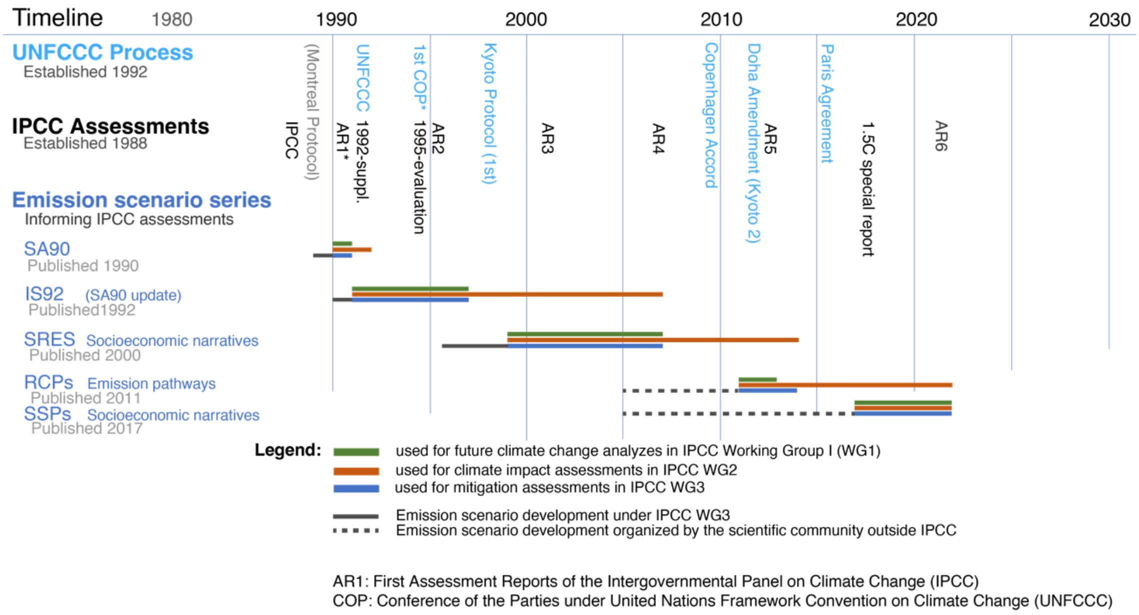


Figure 47. Use of scenarios in the reports of the different IPCC working groups: overview regarding the main outcomes of the Conferences of the Parties (COPs) under the United Nations Framework Convention on Climate Change (UNFCCC), IPCC assessment reports, socio-economic and emissions scenario series and their inclusion in the scenario-based literature that informs IPCC reports (Working Groups I, II, & III), and relevant discussions on scenarios from 1980 to the present. Source: Pedersen et al. (2022a).

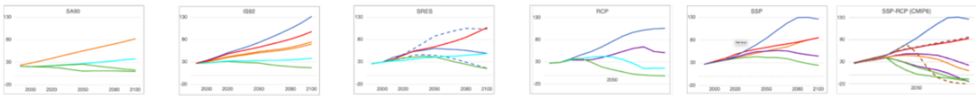
The first three scenario generations (SA90, IS92, and SRES) were developed based on decisions made at intergovernmental meetings, which occurred at the 2nd, 6th, and 12th sessions of the IPCC, respectively (IPCC, 1996a, 1991a, 1989), following Intergovernmental Panel procedures (Bolin, 2007a; IAC, 2010).

The second and third sets of scenarios were developed under specific intergovernmental mandates and terms of reference defined by the same Panel (Leggett et al., 1992b; Nakicenovic and Swart, 2000b). This implied that the different governments involved influenced the production of scenarios, an example being the failure to incorporate climate policies into them.

In 2006, at the IPCC 25th intergovernmental session, it was decided that scenario development should take place externally to the IPCC (IPCC, 2006). Additionally, it was agreed that climate trajectories (radiative forcing) should be decoupled from socio-economic scenarios (IPCC, 2007b; Richard H Moss et al., 2010; van Vuuren et al., 2011b). This resulted from the need to decrease the time needed to produce climate and socio-economic scenarios (Richard H Moss et al., 2010), coupled with the fact that the IPCC mandate only allows for the assessment of existing scientific knowledge (Hulme, 2016), with the creation of socio-economic and emissions scenarios having been the exception until then.

Figure 48 summarizes the four generations of scenario sets, their characteristics, and changes in key variables over time.

	Developed under IPCC mandates			Developed outside IPCC mandates		
Scenario series	SA90	IS92	SRES	RCP	SSP	SSP-RCP
Number of scenarios	4 marker scenarios	6 scenarios	4 narratives (+2 illustrative)	4 pathways	5 narratives (+21 mitigation)*	7 (+2 exp.)**
Development year	1990	1992	2000	2011	2017	2018
Total CO_2 ranges						



	SA90	IS92	SRES	RCP	SSP	SSP-RCP
Reduced regional inequality***	0	0	2 (2)	-	2 (9)	4 (4)
Mitigation scenarios	2	0	0	1	0 (21)	5 (2)

Key variables: Range of projections (yearly average growth rates)

Period	1985-2100	1990-2100	1990-2100	2005-2100	2010-2100	2015-2100
Population	0.7	0.2-1.1	0.3-0.9		0.2-0.7	
GDP (MER)	1.5-2.9	1.1-3.0	2.2-3.0		-	
GDP (PPP)	-	-	-		1.7-3.1	
Total Primary Energy	0.3-1.5	0.4-1.8	0.3-1.7		0.6-1.5	
Cumulative Total CO_2 1990-2100 (Gt C)	440-1600	775-2200	775-2550	500-2100	290-2425	340-2400

* The SSPs are based on 5 narratives: They include the 5 baseline scenarios (+ 21 mitigation scenarios based on the RCPs)
** The SSP-RCP scenarios are climate model experiments used in CMIP6 (Phase 6 of the Climate Model Intercomparison Project).
The emissions SSP-RCP outcomes are related to the SSP socio-economic scenarios (2017): 2 baseline and 5 mitigation scenarios were selected + 2 experimental scenarios.
*** Convergenge scenarios express future worlds that move towards less inequality between world regions (e.g., reduction in regional differences in per capita income, increased interaction)

Figure 48. Emission scenario characteristics for the four generations of emission scenario series SA90, IS92, SRES, and RCP/SSP. a Publication, CO_2 emission ranges, and arbitrary assumption aspects related to critiques. b Ranges of projections for critical variables. Data sources: Scenario databases for SA90, IS92, SRES, RCP, SSP (See SI Chapter 4), Gidden et al. (2018), and IPCC (2005). Source: Pedersen et al. (2022a)

During different generations, emissions scenarios have undergone structural changes (Girod et al., 2009; Richard H Moss et al., 2010), driven by intergovernmental processes (IPCC, 1991a) and scientific assessments (Alcamo et al., 1995a; Parikh, 1992). The scale of these changes is significant and has impacted climate assessments, changing perspectives on possible futures and strategic responses over time. Therefore, emissions scenarios are essential for thinking about future sustainability and possibilities for policy action (Raskin et al., 2005).

Overview of successive scenario definitions and developments, 1988-2020

First generation: SA90 scenarios

This series comprises two baselines (scenario without climate policies) and two "intervention scenarios" (scenarios with climate policies), which analyze five different types of GHG emissions based on assumptions of average GDP growth and climate policy implementation, using a median population projection (IPCC, 1990b, 1990c; Zachariah and Vu, 1987). Eight variants, based on low/high economic growth, were also prepared (IPCC, 1990d) by Dutch and American scientists in the Response Strategies Working Group, which was later consolidated as Working Group III (WG3), dedicated to compiling, and evaluating the scientific production on climate change mitigation (IPCC, 1990e).

The projections resulted from applying an American model that was used by the energy industry, which was modified to include GHGs (IPCC 1990a). This set of socio-economic and emissions scenarios allowed the analysis of a plausible set of climate change projections, developed within Working Group I (WG I), dedicated to compiling and assessing the scientific production on the physical component of climate change (IPCC, 1990f, 1990g). The SA90 scenarios were used in the first IPCC assessment report (AR1).

The second generation: The IS92 updates

This series of scenarios was the first to provide estimates for the full suite of GHGs (IPCC, 1996a). There was an adjustment of the two non-interacting SA90 scenarios with two emissions scenarios like SA90-A (IS92a/b) and two scenarios with higher emissions (IS92e/f) (Pepper et al., 1992a), with medium-high and high cumulative emissions trajectories (IPCC 2000b). The IPCC mandate explicitly excluded the development of new climate policy scenarios (Leggett et al., 1992b). The six scenarios are based on a model developed by authors from the same institutions that created the SA90s. The IS92s were included in the IPCC supplementary report in 1992 (IPCC, 1992) and in scenario literature that helped inform AR2 (WG1, WG2, and WG3), AR3 (WG2), and AR4 (WG2) (IPCC, 2007c, 2001a, 1995). Due to the temporal differences between the impact assessment research cycles, in AR3 (WG2), mostly IS92-based impact assessments were included (IPCC, 2001b), while in AR4 (WG2), a combination of IS92 and SRES were included (IPCC, 2007d).

Third generation: SRES scenarios

The SRES scenario set was the first to consider the concept of narratives/storylines. These socio-economic scenarios interpreted different quantitative futures, describing "economic versus environmental" (A-B) and "global versus regional" (1-2) development in four scenario narrative families. These were represented by four baselines and two illustrative scenarios (A1F and A1T from the rapid global growth scenario family). Additional 34 variations were modeled (Nakicenovic and Swart, 2000a). The SRES included global economic convergence (equality) scenarios (e.g., the A1 and B1 families). This change was based on an IS92 critique (Parikh, 1992), leading to an IPCC evaluation of the IS92 scenarios (Alcamo et al., 1995b; Nakicenovic and Swart, 2000a)

As specified in the IPCC terms of reference, the assumptions excluded population and mitigation policies (Nakicenovic and Swart, 2000b). They included the participation of several modeling teams from various world regions (IPCC 1996a). The set of scenarios was developed through six models, using IAM and building on phase 3 of the Coupled Model Intercomparison Projection (CMIP3) for Europe, Japan, and the United States of America, and included contributions from authors and editors outside the OECD (Nakicenovic and Swart, 2000a). SRES were used in the scenario-based literature that informed AR3 (IPCC, 2001c) and AR4 (IPCC, 2007e).

6.3 Annex III - Categorization of & comparing scenarios across scenario generations

Categorizing scenarios by cumulative emissions (quantifications)

The individual scenarios can be grouped into four categories based on “cumulative emissions 1990-2100” categories as defined by the IPCC (IPCC, 2000): low (0-1099 GtC) (green), medium-low (1100-1429 GtC) (Aquamarine), medium-high (1430-1799 GtC) (orange), and high emissions (1800- GtC) (blue) (Pedersen et al., 2021).

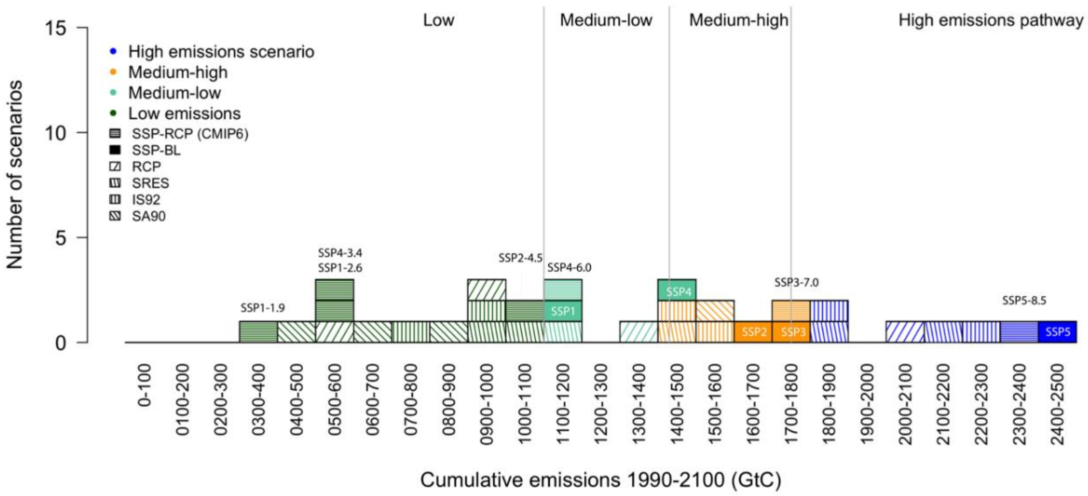


Figure 49. Total global cumulative CO_2 emissions (GtC) from 1990 to 2100 by scenario. Total CO_2 from Land use, industry, and fossil fuels. The Scenarios are illustrated via a histogram of their distribution by scenario groups high-emissions, medium-high, medium-low, and low-emissions scenarios defined by the vertical lines. Panel A: SA90, IS92, SRES marker/illustrative, and SSP-Baseline scenarios by scenario families – 19 baselines & 2 mitigation scenarios. Panel B: histogram of the distribution of SSP baseline and mitigation scenarios by SSP scenario groups – 5 baseline & 21 mitigation scenarios. Regarding the SSPs, Panel A shows the ranges of cumulative emissions for the SSP baseline scenarios and Panel B the ranges of the SSPs when they are linked with the RCP forcing levels (1.9, 2.6, 3.4, 4.5, and 6.0) according to Phase 5 of the Climate Model Intercomparison Project (CMIP5). Data sources: IPCC AR1(IPCC, 1990a) for SA90 and scenario databases for IS92, SRES, RCP, and SSP. High to low emissions categories are defined by IPCC (IPCC, 2000). Source: adapted from Pedersen et al. (2021)

The short-term growth rates of the scenarios do not necessarily reflect the long-term emission trajectory (e.g., several scenarios have a peak-and-decline-shaped trajectory, such as SA90-B, IS92c, SRES-A1B/T/B1, RCP4.5, SSP1, and SSP4).

Table 21 presents the emission scenarios informing IPCC assessment reports 1990-2021 grouped by cumulative total CO_2 emissions. We focus on "marker scenarios" (e.g., SSP baseline (SSP-BL) and SRES marker/illustrative scenarios).

Table 21. The emission scenario generations grouped by cumulative emissions pathways. Scenario series informing assessments for IPCC Assessment Reports 1990-2022. Cumulative emissions 1990-2100 categories as defined by the IPCC (IPCC, 2000): low (0-1099 GtC), medium-low (1100-1429 GtC), medium-high (1430-1799 GtC), and high emissions (1800- GtC). The categorization of cumulative emissions is based on values introduced in IPCC (2000). The emissions estimates are extracted from the scenario databases: IPCC (1990a), Pepper et al. (1992b), Nakicenovic & Swart (2000a), Riahi et al. (2017a), van Vuuren (2011a), Gidden et al. (2019c)

Emission Pathway (Cumulative CO_2 emissions 1990-2100)	**Scenario Series/generations**					
	SA90	**IS92**	**SRES**	**RCP**	**SSP**	**SSP-RCP**
Low emission pathways 0-1099 Gt C	SA90-D: "Acc. Policies" SA90-C "Control policies" SA90-B "Energy efficiency"	IS92c IS92d	B1: Global SD* A1T: Energy transition	RCP2.6 RCP4.5		SSP1-1.9 (1.5C target)** SSP1-2.6 (2C target) SSP2-4.5 (moderate mitigation) SSP4-3.4 SSP5-3.4-OS*** (mitigation beyond 2040)
Medium-low emission pathways 1100-1449 Gt C			B2: local solutions	RCP6.0	SSP1: Global Sustainability SSP4: A divided road	SSP4-6.0 (weak mitigation)
Medium-high emission pathways 1450-1799 Gt C	SA90-A: High emissions (BaU)	IS92a IS92b	A1B: Balanced energy		SSP2: Middle of the road SSP3: Regional rivalry	SSP3-7.0 (baseline) SSP3-LowNTCF***
High emission pathways >1800 Gt C		IS92e IS92f	A1FI: Fossil intensive A2: Self-reliance	RCP8.5	SSP5: Fossil-fuel growth	SSP5-8.5 (baseline)

* Sustainable Development (SD)
**SSP1-1.9 provides the lowest estimate of future forcing matching the most ambitious goals of the Paris Agreement (pursuing efforts to limit the global average temperature increase to 1.5C above pre-industrial levels). SSP1-2.6 represents efforts to limit the global average temperature increase to 2C above pre-industrial levels (1850-1900).
*** Experimental scenarios: SSP5-3.4-OS (OS: Overshoot Scenario = emissions are above Paris temperature targets) and SSP3-LowNTCF (NTCF: near-term climate forcing)

IS92a and IS92b represented updates of SA90-A (Leggett et al., 1992a). IS92a was not labeled BaU but followed similar assumptions and a medium-high emission pathway like the later SSP2' Middle-of-the-road'. The "regional-sustainability" family assumes moderate technology innovation in high-income regions and quantifies global slow emissions growth throughout the century. The "rapid-growth" and "global-sustainability" families generally represent the highest and lowest cumulative emissions pathways, respectively (IPCC, 1990a; Nakicenovic and Swart, 2000a; Pepper et al., 1992b; Riahi et al., 2017a).

IS92f quantifies high emissions throughout the century based on high population, low economic growth, and slow technological change, like SSP3 and A2 (but different from SSP4, assuming continued inequality and energy transition in high-income regions). Although the SSP series do not have a "regional-sustainability" scenario, SSP4 quantifies a medium-low emissions pathway with a trajectory like "global-sustainability" scenarios (peak-and-decline).

Changes across series

The SA90 and IS92 show an almost well-ordered difference between high, medium-high, and low emission scenarios. The high-emission scenarios are the highest from the beginning to the end of the century. In the SRES, the A1B medium-high scenario has a peak-and-decline trajectory. It has higher emissions than the high emission scenarios A1FI and A2 till around 2030. In the IS92 and SRES, the regional rivalry scenarios (IS92f; SRES-A2) are high emission scenarios, while the SSPs produce two regional competitions with lower cumulative emissions (SSP3: medium-high; SSP4: medium-low). See Figure 50.

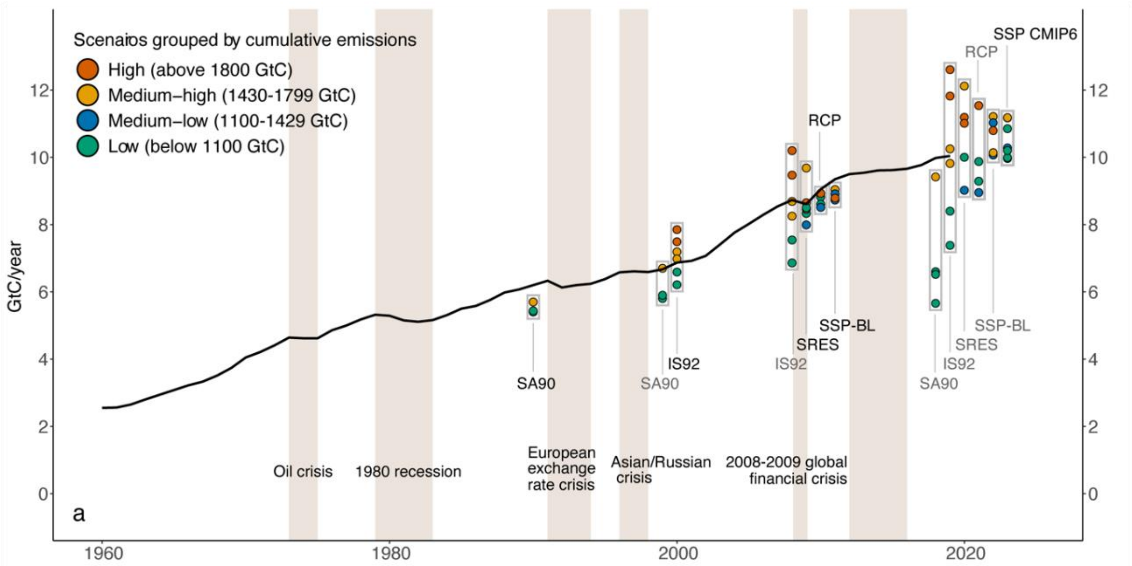


Figure 50. Variations of global estimates for SA90, IS92, SRES, RCP, SSP-BL, and SSP CMIP6 Fossil CO_2 projections 1990-2020. Data source: Scenario databases. Source: Pedersen et al. (2020)

Categorizing by narrative families (storylines and assumptions)

We see that insights into future developments have changed over time when comparing the assumptions and storylines across scenario series. This section analyses the representation of scenarios in families with narratives to organize the scenarios across the four series in a broad range of different types of future developments. Afterward, we compare historical developments, emissions, and drivers and finally analyze historical developments with scenarios. The representation of scenarios in families according to their narratives is a way to organize/categorize the scenarios across the generations. Storylines were developed for the SRES and additionally for the SSPs. The SA90 and IS92 assumptions and quantifications can effectively be related to specific, more extensive narrative descriptions of the later sets. Despite the two earliest generations having more simplified assumptions, we categorize all emission scenarios in five scenario families based on storylines to compare scenarios across all four generations.

Five Main "Scenario families"

Nakicenovic & Swart (2000a) introduced the concept of scenario families and analyzed it further in van Vuuren et al. (2012a). Storylines were developed for the SRES and additionally for the SSPs. The first two series, SA90 and IS92, had assumptions for key variables (IPCC, 1990a; Leggett et al., 1992a) rather than storylines. However, the SA90 and IS92 quantifications can effectively be related to specific, more extensive narrative descriptions of the later sets. The SA90 and IS92 assumptions and quantifications can effectively be related to specific, more extensive narrative descriptions of the latest sets. Despite the two earliest series having more simplified assumptions, it is possible to categorize emissions scenarios in five scenario families based on storylines to compare scenarios across all four series (Table 22).

The general storylines of the scenario families do not necessarily reflect the long-term emission trajectory. The global sustainability scenarios have a peak-and-decline-shaped trajectory, where emissions peak during the century and decline towards 2100. Four other scenarios have a peak-and-decline pathway (two SRES rapid-growth, the SA90 regional sustainability, and an SSP regional competition (SSP4)). To make the differences between individual scenario quantifications transparent, I added the cumulative emissions category in brackets to the Table 22.

Some scenarios have emissions pathways (cumulative emissions 1990-2100) different from most scenarios in the various families (narratives). SRES-A1B is categorized in the "rapid-growth" family according to its narrative. However, its medium-high emission pathway is similar to the "middle of the road" scenarios. The SSP series doesn't have a "regional sustainability" scenario. However, SSP4-BL quantifies a medium-low emissions pathway and a trajectory with the same shape as global sustainability scenarios and SRES-AT1. It is challenging to allocate A1T in both low and high rows because GDP growth is high, but low with emissions growth. The idea of the modeling teams was explicit to show that low emissions could be low because of either technological development (SRES-A1T) or structural change (SRES-B1). Thus, they suggested economic growth and increased consumption (A1T) as an alternative pathway to reducing emissions as achieved by technology advances, stimulated by environment-friendly innovation policies rather than climate policies. This reflects two dominant and opposing views on how emissions can or should be lowered up to today.

Table 22. Scenarios categorized by narrative families. Main five storyline families underlying the SA90, IS92, SRES, and SSP-baseline scenario series. Scenarios are additionally classified according to their cumulative total CO_2 emissions trajectory 1990-2100 (low, medium-low, medium-high, high) based on IPCC (2000). Scenarios with an emissions trajectory different from the general scenarios in their family (grey text) are located twice, and in the family that customarily has similar trajectories (grey text in brackets). The categorization of scenario families is based on van Vuuren et al. (2012a), and the categorization of cumulative emissions is based on values introduced in IPCC (2000). Cumulative emissions pathways are indicated for each scenario (in brackets). Source: Pedersen et al. (2021).

Scenario Narrative Families	**Scenario generations**			
	SA90	**IS92**	**SRES**	**SSP**
"Global sustainability" (Low to medium-low cumulative emissions) *	SA90-C: Control policies (low)* SA90-D: Accelerated policies (low)	IS92c (low)	B1: global solutions (low)	SSP1: SD (medium-low)
"Regional sustainability" (Low to medium-low)	SA90-B: OECD energy efficiency (low)	IS92d (low)	B2: local solutions (Medium-low)	
"Middle of the road" (medium-high)	SA90-A: High emissions (Medium-high)	IS92a IS92b: OECD efficiency (Medium-high)		SSP2: Middle of the road (medium-high)
"Regional competition" (Medium-high to high)		IS92f (high)	A2: Self-reliance (Medium-high)	SSP3: Regional rivalry (medium-high)
				SSP4: A divided road; Regional SD (medium-low)
"Rapid growth" (High to low)		IS92-E (high)	A1FI: Fossil intensive (high) A1B: Balanced energy (Medium-high) A1T: Energy transition (low)	SSP5: Fossil-fuel growth (high)

*Emissions pathways Cumulative total CO_2 emissions 1990-2100. Total includes land use change and fossil fuel & industry carbon emissions.

Therefore, the allocation of some scenarios (i.e., A1B, A1T, SSP4) according to emissions quantifications goes across the scenario narrative family category (dependent on the selected decisive scenario element). For example, A1T could be categorized in the "rapid-growth" family because GDP growth is high. Also, in the "global-sustainability/low-emissions" category since cumulative emissions are low.

None of the series describe degrowth or zero-growth scenarios. However, also such a scenario would be plausible, e.g., as a result of externalities of the current economic system, such as material scarcity, increasing climate impacts, ecosystem breakdown, or finance system instability (Costanza, 2014; Meadows et al., 1972; Ngo et al., 2019) as well as a political choice to address such risks (Ward et al., 2016). However, in an IPCC context, this was considered to have a small likelihood and low political acceptability at the time (based on interviews. See Pedersen et al. (2021)).

The assumptions underlying the storylines

Developing the SA90 scenarios in the late 1980s, modelers made assumptions on what would be possible future socio-economic developments and associated GHG emissions (Bolin, 2007b; IPCC, 1990a). The developers provided no narratives other than lower, average, and higher growth and different levels of climate policy. This involved one baseline, called both "High Emissions" and "Business-as-Usual (BaU)" (assuming few or no steps taken to limit GHG emissions); one "low emissions", and two 'intervention' scenarios (including mitigation policies). No intervention scenarios were included in IS92 and SRES. The lowest IS92-scenario, IS92c, had emission levels and assumptions comparable to an intervention scenario that was argued to be the side effect of non-climate/environmental policies (Alcamo et al. 1995) and global sustainability SRES-B1. Elaboration of the scenarios at the regional level was less well developed (IPCC, 1990a). Thus global (in-)equality considerations or convergence assumptions were less explicit. Inequality later became one of the governing principles of the SRES and SSP assumptions (Nakicenovic and Swart, 2000b; O'Neill et al., 2014).

Global sustainability scenarios: The scenarios quantify a peak and decline in emissions from about 6 GtC/year in 1990 to a range of 3-7 GtC/year by 2100. They assume a shift in values from economic growth to sustainable development (e.g., climate or environmental policy assumptions). No intervention scenarios (climate policy assumptions) were included in IS92 and SRES. After the SA90s, policy assumptions were excluded via the IPCC mandate for IS92 (IPCC, 1991b; Leggett et al., 1992a) and SRES (IPCC, 1996b; Nakicenovic and Swart, 2000a). Thus, both IS92 and SRES evolved in the absence of climate policy assumptions (Leggett et al., 1992a; Nakicenovic and Swart, 2000a). However, low emissions scenarios were included based on other assumptions, such as side effects of non-climate/environmental policies (Alcamo et al. 1995) and technological development (Nakicenovic and Swart, 2000a). Emissions by 2100 range from 3 to 7 GtC/year (Annual growth rates: -0.4 to 0.3%).

Regional sustainability: Scenarios in this family assume moderate technology innovation in high-income regions and quantify global slow emissions growth throughout the century. In these scenarios, emissions will increase to between 10 and 14 GtC/year by 2100 (Annual growth rates: 0.6-0.7%).

Middle-of-the-road: These scenarios follow similar assumptions and medium-high emission pathways. The original Business-as-Usual (BaU) scenario in the SA90 was criticized at IPCC sessions, and thus this label was officially excluded in the successive scenario terminologies (IPCC, 1991b). However, this type of scenario was represented in the IS92 via two scenarios (Leggett et al., 1992a) and in the SSPs, labeled 'Middle-of-the-road'. The SRES series does not have such a scenario narrative. The scenarios in this family increase from about 6 GtC/year in 1990 to about 20 GtC/year in 2100 (Annual growth rates: 0.8-1.3%).

Regional competition: Generally, these scenarios assume low environmental regulation, high population, weak economic growth, and slow technological change. Three scenarios (SSP3, A2, and IS92f) fit this description best. They project an increase in the range of 22-28 GtC/year by 2100 (Annual growth rates: 1.2-1.7%). One SSP scenario assumes continued global inequality with energy transitions in high-income regions and thus quantifies a peak-and-decline emissions pathway with 12 GtC/year by 2100 (Annual growth rates: 0.7%).

Rapid growth: These scenarios assume rapid economic growth. In most rapid growth scenarios, growth is provided via a fossil-fuel intensive energy sector and quantifies emissions in the range of 30-35 GtC/year by 2100 (Annual growth rates: 1.5-1.8%). As mentioned earlier, two of the SRES rapid-growth quantify high economic growth but medium-high and low cumulative emissions because of various degrees of the energy transition. They quantify annual growth rates in the range of -0.3 to 0.7%.

The storyline focus of the scenario sets has changed over time: from energy mix and efficiency (SA90) to population, income, and fossil fuel resources (IS92), to "regional vs. global" and "economic vs. environmental" (SRES) (Girod et al., 2009). Most recently, there has been a shift to energy system demand and supply characteristics as a function of a set of demographic and economic drivers broader than previous scenarios, providing a more solid basis for complementary mitigation and adaptation analyses with the SSP/RCP (Riahi et al., 2017).

RCP/SSP scenarios were designed as a new framework utilized to design scenarios that combine socio-economic and technological development. Aimed to be used in multiple research communities, exploring interactions between human societies and the natural environment (Fujimori et al., 2017).

At one end of the emissions range, a family of optimistic scenarios explores worlds in which governments join forces, e.g., through adopting environmental or other sustainable development policies, or by other means, global advances in low-carbon technologies are enforced. At the same time, poverty and inequality are reduced (Global sustainability). Because of their terms of reference, IS92 and SRES explicitly exclude specific climate or greenhouse gas emissions reduction policies. At the other end of the emissions range, scenarios include rapid global economic growth based on fossil fuels and reduced inequality (rapid growth) or examine countries that upgrade their use of cheap fossil fuels, pursuing national economic growth (regional competition) (Pedersen et al., 2021, 2022a).

Some remarks on individual scenarios (alternative choices of categorizations)

According to emissions quantifications, the allocation of some scenarios (i.e., A1B, A1T, SSP4) is more subjective (dependent on the selected decisive scenario element) than most. For example, A1T could be categorized in the "rapid-growth" family because GDP growth is high (main choice in table 3) but also in the "global-sustainability/low-emissions" category if one would focus on the low emissions growth (see Table 21 & Table 22). The idea of the modeling teams was explicit to show that emissions could be low because of either technological development (A1T) or structural change (B1). This reflects two dominant and still important opposing views on how emissions can or should be lowered in the IS92, SRES, and SSP series.

It was argued that IS92b was an intervention scenario because it included policy assumptions related to the Montreal Protocol (Girod et al., 2009). The Montreal Protocol was an international treaty designed to protect the ozone layer (UN, 1989) and not to be considered a climate treaty like the Kyoto Protocol (UNFCCC/COP, 1997) and Paris Agreement (UNFCCC, 2015). The Montreal Protocol reduced CFC gasses (Chlorofluorocarbons) and does not include climate gasses. However, it had a negative side effect since CFC was substituted with HFCs (Hydrofluorocarbons), which has a strong global warming potential (IPCC, 2014c).

Later the Kigali Amendment, ratified by 72 countries by 2019, aims to reduce the MP substitute gasses HFC, HCFC, and CFC gas emissions. Scientists estimate that the Kigali agreement can reduce temperature change by 0.4°C by 2100 (McGrath, 2016; Riahi et al., 2017a; UNEP, 2016).

The lowest scenarios (IS92c) and global sustainability SRES-B1 had emission levels and assumptions comparable to an intervention scenario argued to be the side effect of non-climate/environmental policies (Alcamo et al., 1995b). The storyline focus of the series has changed from energy mix and efficiency (SA90) to population, income, and fossil fuel resources – with assumptions regarding cost reductions over time, resources, and technological change (IS92), to "regional vs. global" and "economic vs. environmental" (SRES series) (Girod et al., 2009; Pepper et al., 1992b) to energy structures and its coupling with more advanced demographic and economic drivers, as well as future implications for mitigation and adaptation (Riahi et al., 2017a).

Elaboration of the scenarios at the regional level was less well developed (IPCC, 1990a), and thus, global (in-)equality considerations were less explicit. This later became one of the governing principles of the SRES and SSP assumptions (Nakicenovic and Swart, 2000b; O'Neill et al., 2014). IS92a and IS92b represented updates of SA90-A (Leggett et al., 1992a). IS92a was not labeled BaU but followed similar assumptions and a medium-high emission pathway similar to the later SSP2' Middle-of-the-road'.

IS92f quantifies high emissions throughout the century based on high population, low economic growth, and slow technological change, similar to SSP3 and A2 (but different from SSP4, assuming continued inequality and energy transition in high-income regions). Although the SSP series do not have a "regional-sustainability" scenario, SSP4 quantifies a medium-low emissions pathway with a trajectory similar to "global-sustainability" scenarios (peak-and-decline).

The "regional-sustainability" family assumes moderate technology innovation in high-income regions and quantifies global slow emissions growth throughout the century. The "rapid-growth" and "global-sustainability" families generally represent the highest and lowest cumulative emissions pathways, respectively (IPCC, 1990a; Nakicenovic and Swart, 2000a; Pepper et al., 1992b; Riahi et al., 2017a).